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THE

# QUARTERLY JOURNAL

OF THE

# GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE ASSISTANT-SECRETARY OF THE GEOLOGICAL SOCIETY.

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Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant.
—*Novum Organum, Præfatio.*

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## CORRIGENDA.

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*Proc.* p. 25, line 7 from bottom, *for* "Lausaune" *read* "Lausanne."

*Proc.* p. 31, last line, *for* "Harisron" *read* "Harrison."

Page 255, line 4 from top, *for* "mountains" *read* "mountain."

Page 255, line 2 from bottom, *for* "sufficient to" *read* "sufficiently hard, to."

Page 256, line 20 from top, *for* "eruptions" *read* "eruptives."

Page 257, line 4 from bottom, *for* "stock" *read* "boss."

Page 259, line 17 from top, *for* "non-existent" *read* "non-resistant."

Page 262, line 9 from top, *for* "besides" *read* "outside of."

Page 263, line 2 from bottom, *for* "magnetic" *read* "magmatic."

Pages 444, 445. The section described as picrite-porphyrite has since been determined by Prof. Rosenbusch as diabase.

Page 447, line 11 from bottom, *for* "pilotaxitic" *read* "hyalopilitic."

THE

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## 1. North-Italian Bryozoa. By Arthur Wm. Waters, Esq., F.G.S. (Read June 4, 1890.)

[Plates I., II., III., IV.]

Chilostomata.—The Bryozoa dealt with in this paper are, for the most part, from well-known localities in the Vicentine, as Val di Lonte, Montecchio Maggiore, and Brendola. Most of them have been described by Reuss, but at a time when chief attention was paid to the zoarial mode of growth (the shape of the oral aperture and other zoœcial characters being considered to be of secondary importance) and when the avicularia and ovicells did not receive the attention now given to them.

The first paper treating of North-Italian Bryozoa, of this series, is one by Reuss *, in which he refers to a number of species as from an unknown locality in the Vienna Basin; but these, he subsequently † found, came from the Val di Lonte, called also Val dell' Onte (but the exact position is Casa Fortuna), in the Vicentine. Although this correction has been made, references are constantly given which show that authors overlook this rectification.

From a similar marl in Montecchio Maggiore, a few miles further south, Reuss also described ‡ a number of others, and a couple from Brendola, in the Colle Berici, south of Vicenza; and from Crosaro, some distance to the north-east, a few which appear to be of nearly the same age. In the first three localities the marl contains a very

* "Die fossilen Polyparien des Wiener Tertiärbeckens," Haidinger's 'Naturwissenschaftliche Abhandl.' vol. ii.

† "Foss. Bryozoen des Oest.-Ung. Miocäns," Denkschr. Ak. Wissensch. Wien, vol. xxxiii.

‡ "Die fossilen Anthozoen und Bryozoen d. Schichtengruppe von Crosaro," Denkschr. Akad. Wissensch. Wien, vol. xxix. This paper is referred to in the following pages as "Bryoz. von Crosaro."

similar fauna; and, having collected from all, I found the Brendola beds the most instructive, and there the preservation is the best *.

The late Dr. G. B. Gottardi † has also given a list of species from Montecchio Maggiore; but he follows the generic and specific names given by Reuss, even where Reuss himself had subsequently introduced modifications, or reduced the synonymy; and nothing is added to our knowledge of the characters, so that we do not know what qualifications Gottardi possessed for making the determinations.

Besides these already-known localities, I have collected from two in the Veronese which are of considerable geological interest; and both are new localities. The first is Ferrara di Monte Baldo. The mountain is on the east of the Lake of Garda, and the deposit occurs at about 4670 feet above sea-level and about 1750 feet above the village (by the path leading to Madonna del Neve, past the Austrian frontier) as a thin bed, where, although the Bryozoa are numerous, they are very badly preserved; and the same remark will apply to the second locality, Ronzo, near Mori, in the Tirol, north of the Lake of Garda.

[Since this paper was read, I have again visited North Italy, and collected from Malo and Priabona, both near Schio in the Vicentine; and also from near Ferrara di Monte Baldo. I did not, however, find the beds uncovered at the locality mentioned in the paper; but about halfway between the village and the frontier (marked Novezzina in the Austrian maps) a blue marl attains to a considerable thickness, containing many Bryozoa. Besides the species mentioned, *Microporella distoma*, B., occurs at Malo and Novezzina. —A. W. W., Dec. 24, 1890.]

The Ferrara deposit lies above a series of beds commencing with those containing large *Nummulites*, as *N. Brongniarti*, &c., then beds with *Cancer punctulatus*, &c., then with *Serpula spirulæa*,—in fact similar to the Vicentine series.

Many of the species are known from the Lower Tertiaries of other parts of Europe; Reuss, in a series of papers, has given descriptions from several places in the north of Europe, as Söllingen, Latdorf, &c.; and recently Koschinsky ‡ has published an important work on the South-Bavarian Tertiary Bryozoa. Pergens § also has given lists and some descriptions of species from Hungarian and other localities.

The Vicentine fossils are dark in hue, and this makes the study of them difficult and very fatiguing, especially as the marl is often hardened in the cavities, obscuring the characters. The specimens

* Grancona, alluded to in the paper, is near Lonigo, in the Colle Berici; Bocca di Sciesa is between the two.

† "Briozoi Fossili di Montecchio Maggiore," Atti Soc. Trent. di Sc. Nat. vol. ix. pp. 297–308.

‡ "Bryozoenfauna der älteren Tertiärschichten des südlichen Bayerns," 'Palæontographica,' vol. xxxii.

§ 'Les Bryozoaires du Syst. Montien,' 1886 (Louvain); "Bryoz. Foss. de Kolosvar," "Bryoz. de Tasmajdan," Bull. Soc. Malac. de Belgique, vol. xxii.; "Bryoz. von Wola Lu'zanska," Bull. Soc. Belg. Géol. Hydrol. &c. vol. iii.

have mostly been collected many years ago, and, when returning to the work, it has often been possible to further clean them by soaking in water, then brushing with a camel-hair pencil, drying, and repeating the process. Recently, however, I have obtained very much better results by placing the fossils in a saturated solution of sulphate of soda and allowing it to crystallize. When this is washed out it loosens the matrix within the apertures, and they are thus more thoroughly cleaned than would be possible by ordinary means.

Although all of Reuss's works were beautifully illustrated, the figures were rather the artist's than the naturalist's figures, one zoœcium being drawn and then identically repeated several times; but this geometrical regularity does not often occur in nature. The figures now given are supplementary, to show the characters to which I allude.

Though considering a revision now required, I would point out how great an advance Reuss's work was upon what had been done before; and that he gave more attention to zoœcial characters than his predecessors had, often forming groups according to the nature of the surface and the presence of oral spines or avicularia. It is true that very few of these groups will now stand, but in this way the study of the value of the characters has been made possible without adding to the number of generic names.

There are many cases of a species occurring in both the incrusting and erect form; some show considerable difference in zoarial shape, and there are interesting instances of great range, so that different parts of the same colony have widely divergent appearance.

Perhaps the most noticeable case is *Cellepora proteiformis*, which commences in a flat *Eschara*-form, on which, however, single zoœcia may be raised (figure 14); but in later stages the zoœcia are piled up irregularly, often several layers thick. *Lepralia bisulca* varies much in appearance; and *Porina coronata* may either have the zoœcia distinct or scarcely distinguishable. There may be more or less of a peristome in front, and the number of large pores or avicularia around the aperture is very variable; further, the central avicularium may be absent, may be moderately large, or developed into a gigantic raised spatulate avicularium. When the aperture has a closure the appearance is further modified. *Porina papillosa*, with or without avicularia or prolonged zoœcia, also has a very variable appearance. There are forms with *Lunulites*-mode of growth with the zoœcia of *Membranipora*, *Cellepora*, and *Lepralia*.

As we thus obtain more exact acquaintance with the Bryozoa of past times, we shall in some cases be enabled to check the correctness of the principles of present classification and gain new ideas as to relationship; but fresh difficulties are brought before us.

Among the points brought forward, the discovery of *Catenicella* is of special interest as bearing upon the relationship of this genus.

*Fedora excelsa* is interesting, from the way in which it grows from the apex of the colony,—from occurring on both sides of the Alps,—and from the genus being represented by one recent form dredged by the 'Travailleur.'

*List of Species.*

| | Living. | Val di Lonte. | Montecchio Maggiore. | Brendola. | Ferrara di Monte Baldo. | Ronzo. | Crosaro. | Götzreuth. | Wola Lu'zanska. | Other Localities. |
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| 4. Scrupocellaria elliptica, *Rss.* | ... | * | * | | | | | | | |
| 5. —— gracilis, *Rss.* | ... | * | * | ... | ... | ... | ... | ... | ... | Gaas. |
| 6. —— brendolensis, sp. nov. | ... | ... | * | * | | | | | | |
| 7. —— montecchiensis, sp. nov. | ... | ... | * | | | | | | | |
| 8. Bactridium Hagenowi, *Rss.* | ... | * | * | * | ... | ... | ... | ... | ... | Lower Eocene of Mons; Malo. |
| 9. Cellaria Reussi, *d'Orb.* | ? | * | * | * | ... | ... | * | ... | ... | Miocene of Vienna. |
| 10. Onychocella angulosa, *Rss.* | * | * | * | * | * | ... | * | * | * | Cretaceous; Miocene of Vienna; Malo; Priabona. |
| 11. Vibracella trapezoidea, *Rss.* | ... | * | * | * | * | ... | ... | ... | ... | Bocca di Sciesa; Malo |
| 12. Membranipora macrostoma, *Rss.* | ... | * | * | * | * | * | ... | * | ... | Miocene of Vienna; Wieliczka. |
| 13. —— tenuirostris, *H.* | * | * | * | | | | | | | |
| 14. —— Dumerilii, *Aud.* | * | * | * | * | ... | ... | ... | ... | ... | Crag; Pliocene of Italy. |
| 15. —— Rosselii, *Aud.* | * | * | * | * | ... | ... | ... | * | | |
| 16. —— patellaria, *Moll* | * | ... | * | | | | | | | |
| 17. —— appendiculata, *Rss.* | * | * | * | * | | | | | | |
| 18. —— Hookeri, *Haime* | ... | * | * | ... | ... | ... | * | | | |
| 19. Micropora coriacea, *Esp.* | * | * | * | * | | | | | | |
| 20. —— polysticha, *Rss.* | ... | * | * | * | * | ... | ... | * | | |
| 21. —— parallela, *Rss.* | ... | * | * | * | ... | ... | * | ... | ... | Novezzina. |
| 22. —— articulata, sp. nov. | ... | ... | * | | | | | | | |
| 23. —— cucullata, *Rss.* | ... | * | * | * | * | * | * | * | * | Miocene of Vienna; Latdorf; Astrupp; Pianosa; Malo; Priabona. |
| 24. Cribrilina radiata, *Moll* | * | * | * | * | ... | ... | ... | ... | * | Söllingen; Miocene, Austria, &c.; Pliocene, Italy, Australia. |
| 25. —— chelys, *Kosch.* | ... | * | ... | * | ... | ... | ... | * | * | Priabona; Grancona. |
| 26. —— crenatimargo, *Rss.* | ... | * | * | * | * | ... | ... | ... | * | Malo. |
| 27. Monoporella sparsipora, *Rss.* | ... | * | * | * | * | ... | ... | ... | ... | Cretaceous; Priabona; Malo. |
| 28. Lepralia subchartacea, *d'Orb.* | ... | * | * | * | ... | ... | ... | ... | ... | Pyrenees; Hungary. |
| 29. —— semilævis, *Rss.* | ... | * | * | * | * | * | ... | ... | ... | Galicia and Hungary; Malo; Priabona. |
| 30. —— bisulca, *Rss.* | ... | * | * | * | * | * | * | * | .. | Hungary; Malo. |
| 31. —— nodulifera, *Rss.* | ... | * | * | * | * | * | ... | * | * | Malo; Priabona. |
| 32. —— impressa, *Rss.* | ... | * | ... | * | ... | ... | ... | ... | * | |
| 33. —— excentrica, *Rss.* | ... | ... | * | ... | ... | ... | * | ... | ... | |
| 34. —— syringopora, *Rss.* | ... | * | * | * | * | * | * | * | ... | Priabona; Malo. |
| 35. —— bericensis, sp. nov. | ... | ... | ... | ... | ... | ... | ... | ... | ... | Bocca di Sciesa. |
| 36. —— lontensis, sp. nov. | ... | * | * | * | * | * | * | ... | ... | Malo. |
| 37. Smittia coccinea, *Abild.* | * | ... | * | * | | | | | | |
| 38. —— ——, var. alifera, *Rss.* | ... | * | * | * | * | * | ... | ... | ... | Hungary; Malo. |
| 39. —— Landsborovii, var. cheilopora, *Rss* | ... | ... | ... | * | ... | ... | ... | ... | ... | Moravia. |
| 40. —— porrigens, *Rss.* | ... | ... | * | * | ... | ... | ... | ... | ... | Söllingen. |
| 41. —— exarata, *Rss.* | ... | * | * | * | * | | | | | |
| 42. Porella imbricata, *Rss.* | ... | * | * | * | | | | | | |
| 43. —— marsupium, var. porifera, *H.* | * | ... | ... | * | * | ... | ... | ... | ... | Fossil, New Zealand. |
| 44. Rhamphostomella brendolensis, sp. nov. | ... | * | ? | * | | | | | | |
| 45. Porina coronata, *Rss.* | ... | * | * | * | * | * | * | * | * | Eocene of Hungary; Malo; Priabona. |
| 46. —— duplicata, *Rss.* | ... | * | * | * | * | * | ... | ... | ... | Hungary; Malo. |
| 47. —— papillosa, *Rss.* | ... | * | * | * | * | * | * | * | ... | Oberburg, Neustift, Styria; Malo. |
| 48. —— bioculata, sp. nov. | ... | ... | ... | * | | | | | | |
| 49. Schizoporella Hoernesi, *Rss.* | ... | * | * | * | ... | ... | ... | * | ... | Curdies Creek. |
| 50. —— squamoidea, *Rss.* | ... | * | * | * | | | | | | |
| 51. —— unicornis, *Johnst.* | ... | ... | * | ... | ... | ... | ... | ... | ... | Miocene and Pliocene. |
| 52. —— serrulata, *Rss.* | ... | ... | * | ... | ... | ... | ... | ... | ... | Eisenstadt. |
| 53. —— Omboni, *Gott.* | ... | * | G | * | ... | ... | ... | ... | ... | Malo. |
| 54. —— phymatopora, *Rss.* | ... | * | ... | * | ... | ... | ... | ... | ... | Lower Eocene of Mons. |
| 55. —— Schreibersi, *Rss.* | ... | * | * | * | ... | ... | ... | ... | ... | Hungary. |
| 56. —— ternata, *Rss.* | ... | * | * | * | | | | | | |
| 57. Fedora excelsa, *Kosch.* | ... | ... | ... | ... | ... | ... | ... | * | ... | Brentonico, Bocca di Sciesa, Spiassi; Malo. |
| 58. Retepora tuberculata, *Rss.* | ... | * | ... | * | | | | | | |
| 59. —— elegans, *Rss.* | ... | * | ... | * | | | | | | |
| 60. Cellepora proteiformis, *Rss.* | ... | * | * | * | * | * | ... | ... | * | |
| 61. —— oligostigma, *Rss.* | ... | ... | * | ... | ... | ... | * | | | |
| 62. —— pertusa, *Sm.* | * | * | * | | | | | | | |
| 63. Stichoporina simplex, *Kosch.* | * | ... | ... | * | ... | * | ... | * | ... | Novezzina. |
| 64. Batopora multiradiata, *Rss.* | ... | * | * | * | * | * | ... | ... | ... | Priabona, Eocene of Bavaria and Hungary; Malo. |
| 65. —— Stoliczkai, *Rss.* | ... | ... | G | * | | | | | | |
| 66. Lunulites quadrata, *Rss.* | ... | ... | ... | ... | ... | ... | ... | ... | ... | Between Sarego and Grotte, Colle Berici. |

With regard to structure, the closure of *Porina coronata* and *Lepralia syringopora* by a plate with a tubule in the centre is somewhat surprising, as this structure was supposed to be exclusively characteristic of the *Cyclostomata*. The plate is at some distance above the oral aperture.

Some of the erect *Eschara*-forms have the zooecia at the side opposite, others alternate; and as this may be a useful specific character, it has been mentioned in the diagnosis; but it does not appear to have generic value.

The position of these Bryozoan beds has been fairly worked out. Suess *, in 1861, placed them above the Priabona beds and below those of Sangonini. They are the "F." of Bayan †, or Upper Eocene. Professors Hébert and Munier-Chalmas ‡ have also examined the stratigraphical position of the Vicentine beds, and they place the "marne" of Brendola, &c., below the Crosaro and above the Granella beds, but as part of a "même ensemble," considering the Brendola beds as Upper Eocene and equivalents of those of Biarritz. It will thus be seen that there is agreement in the views, and that the Bryozoa may be considered as of Bartonian age and may be called Upper Eocene. From their position the earlier writers called them Miocene. To some of these points I may have to refer more fully when dealing with the *Cyclostomata*.

1. ? Catenaria tenerrima (Reuss). (Pl. I. fig. 11.)

*Crisidia vindobonensis*, Reuss, Foss. Polyp. Wien. Tert. p. 54, pl. vii. fig. 25.

*Unicrisia tenerrima*, Reuss, Bryoz. von Crosaro, p. 279, pl. xxxiv. fig. 7.

This is clearly not Cyclostomatous, as Reuss supposed, and, although it differs in some respects from any living *Catenaria*, it seems to find its place among them. It is not articulated, and the connecting tube is broken off in various positions. The aperture is terminal and seems to have a very wide sinus on the proximal border.

*Loc.* Val di Lonte (*Rss.*); Brendola; Montecchio Maggiore; Ferrara di Monte Baldo.

2. Catenicella septentrionalis, sp. nov. (Pl. I. figs. 1–8.)

The globulæ are amphora-shaped, perforated on the front, with an acute avicularium at each upper corner. Oral aperture nearly orbicular, with the lower margin emarginate; the region round the aperture somewhat elevated. The dorsal surface is sometimes very slightly keeled.

From Montecchio Maggiore there are several uni- and bi-globulæ; but besides there is one with three zooecial cells (fig. 3), and another with four (figs. 4, 5). This is most interesting, as showing that

* Atti della Soc. Ital. di Sc. Nat. di Milano, 1861; and "Ueber d. Gliederung des Vicent. Tert.," Sitz. k. Akad. d. Wissenschaft., 1868.

† "Sur les Tert. de la Vénét.," Bull. Soc. Géol. France, sér. 2, vol. xxvii.

‡ Comptes Rendus de l'Acad. des Sc. vol. lxxxv. p. 259 & pp. 320.

short internodes containing one, two, or even three zoœcia must not be made an absolute generic character, although all living forms are built up of these short beads. The range in this case supports such forms as *C. internodia*, Waters, and *C. continua*, W., being placed with the *Catenicellidæ*. Fig. 8 is a long internode with very long ovicells, but the structure of the zoœcia and of the dorsal surface is the same as in those with shorter nodes, so that we seem to have a series from the uniglobular (fig. 1); though it may be a question whether fig. 8 should not be called a variety.

*Loc.* Montecchio Maggiore.

3. Catenicella continua, sp. nov. (Pl. I. figs. 9, 10.)

Zoarium with long internodes, zoœcia on the anterior surface distinct; vittæ at each side of the zoœcium, and a small triangular avicularium at each outer corner. Oral aperture rounded above, straight below, and there is either a suboral pore or a portion of the wall is thinner below the aperture. On the dorsal surface there is a curved vitta about the middle of the zoœcium. In the long internodes and in other respects this is closely allied to *Catenicella internodia*, Waters (Quart. Journ. Geol. Soc. vol. xxxvii. p. 318, pl. xvi. figs. 78, 79), fossil from Curdies Creek, Australia, a form which I placed under *Catenicella* on account of the distinct vittæ; and the discovery of *C. septentrionalis*, Waters, with occasional multilocular internodes indicates that I was probably right in not separating the Australian fossil from the *Catenicellidæ*.

*Loc.* Fossil: Montecchio Maggiore; Brendola.

4. Scrupocellaria elliptica (Reuss). (Pl. I. figs. 16, 17.)

*Bactridium ellipticum*, Reuss, Foss. Polyp. Wien. Tert. p. 56, pl. ix. figs. 7, 8.

*Scrupocellaria elliptica*, Reuss, Bryoz. von Crosaro, p. 260, pl. xxix. fig. 3; Foss. Bryoz. Oest.-Ung. Mioc. p. 148, pl. xi. figs. 1–9.

*Bactridium granuliferum*, Reuss, Polyp. Wien. Tert. p. 56, pl. ix. fig. 6.

The specimen figured from Montecchio Maggiore has an avicularium below the aperture; but other specimens with the characteristic dorsal surface have no suboral avicularium, and it is an open question whether they should be specifically separated. In recent *Caberea* we find parts of the same colony with an avicularium to each zoœcium, while in other parts they are only occasionally found. I cannot agree with Mr. Hincks in identifying the British form with the fossil, and would suggest that the former stands as *S. inermis*, Norm.

*Loc.* Val di Lonte (*Rss.*); Gaas, S. France; Austrian and Hungarian Miocene; Montecchio Maggiore.

5. Scrupocellaria gracilis, Reuss. (Pl. I. figs. 12, 13.)

*Scrupocellaria gracilis*, Reuss, Bryoz. von Crosaro, p. 260, pl. xxix. fig. 4; Reuss, "Fauna von Gaas," Sitzungsber. Ak. Wissensch. Wien, vol. lvii. p. 466.

A specimen from Montecchio Maggiore seems to be of this species. It is without avicularia on either surface; but at the outer angle of each zooecium there has been a vibraculum (or strong spine), and the vibracular chamber is tubular. There has been a scutum over the front. I do not find in any of my specimens of *Scrupocellaria* from North Italy that there has been an avicularium at the outer angle. Reuss seems to have taken the vibraculum for an avicularium.

*Loc.* Val di Lonte and Gaas (*Rss.*); Montecchio Maggiore.

6. Scrupocellaria brendolensis, sp. nov. (Pl. I. figs. 14, 15.)

The opesial aperture is about one half of the length of the zooecium; near the middle on the inner side the aperture is contracted, no doubt by the base of the scutum; below the aperture there is a triangular avicularium directed outwards; at the upper outer angle there has been a vibracular appendage or a spine. On the dorsal surface there is a vibraculum to each zooecium, with the base attached in a small semicircular chamber near the inner edge of the zooecium.

This would seem related to *S. scabra*, but differs from it in not having any avicularium at the outer upper angle.

*Loc.* San Clementa (Montecchio Maggiore); Brendola.

7. Scrupocellaria montecchiensis, sp. nov. (Pl. I. figs. 21, 22.)

The specimen figured cannot be identified with any of the others, and it therefore seems advisable to give it a name, though at best the determination of fragments of *Scrupocellariæ* is not very satisfactory.

The aperture is very large; there has been no scutum; and the vibracular chamber on the dorsal surface is very large, so that the external prolongation is also seen from the front.

*Loc.* Montecchio Maggiore.

8. Bactridium Hagenowi, Reuss. (Pl. I. figs. 18, 19.)

*Bactridium Hagenowi*, Reuss, Foss. Polyp. Wien. Tert. p. 57, pl. v. fig. 28; Bryoz. von Crosaro, p. 266, pl. xxxi. figs. 5, 6.

The aperture is Schizoporellidan, with a wide sinus. The groove on the dorsal surface is usually very wide and deep, as figured by Reuss, but at other times there is not more than a divisional line.

In the mode of growth this seems nearly related to *Urceolipora* and to *Ichthyaria oculata*, B.

*Loc.* Val di Lonte (*Reuss & Waters*); Brendola; Montecchio Maggiore; Malo; Lower Eocene of Mons (*Mun. & Perg.*).

9. Cellaria Reussi, d'Orb.

*Cellaria marginata*, Reuss (pars), Foss. Polyp. Wien. Tert. p. 59, pl. vii. fig. 29.

*Vincularia Reussi*, d'Orbigny, Pal. Fr. vol. v. p. 60.

*Salicornaria Reussi*, Reuss, Bryoz. von Crosaro, p. 261, pl. xxix. fig. 5.

There are only small fragments of this, which are without ovicells or avicularia, so that it is difficult to say which are its nearest allies; and in the absence of these characters there is nothing to distinguish it from *C. bicornis*, B., and *C. tenuirostris*, B., or *C. ovicellosa*, W.

At first Reuss united it with *C. fistulosa*; but he afterwards saw that they were distinct. Manzoni, however, subsequently considered them synonymous; but in this I cannot agree.

*Loc.* Val di Lonte and Montecchio Maggiore (*Rss.*); Miocene of Vienna (*Rss.*): Brendola; Crosaro.

## ONYCHOCELLA.

Several attempts have been made to group the Membraniporæ into fresh genera, but there has been very little success, as divisions have so often been based, not on fresh characters, but only on variation in degree of common ones—as, for instance, the sloping inwards of the wall of the area, though no doubt fresh characters will ultimately be found permitting of a division of the genus.

There is, however, one section which may be separated, even though the limits scarcely admit of exact definition at present. It is only represented by two or three * living species; but was extremely abundant in Cretaceous times. Jullien † first attempted separation, based upon the nature of the large vicarious avicularia, of which the mandible is attached to the membranous cover, and there is no bar across the calcareous avicularian opening; also, as I have pointed out ‡, there are free chitinous appendages at each side of the base of the mandible. The avicularian opening is, therefore, simple, and usually oval, or nearly round, and the mandibles, as far as known, are winged, and this also obtains in *Membranipora permunita*, *Micropora lepida*, H., and *Foveolaria falcifera*, B.

Jullien established a family, of which the generic divisions were based principally upon the outline shape of the zoarium, and partly upon the shape of the opesia; but these are very uncertain characters for generic divisions, as may be seen from my figure of the recent *Membranipora angulosa* §, and also in fossil specimens. On this account, I am quite unable to follow Jullien with regard to the other genera into which he divides his family, and only accept the genus *Onychocella*. Besides the points to which Jullien drew attention, I would add that in *Onychocella angulosa* there are trabeculæ bordering the operculum. This is general in *Cellaria*, as pointed out by Mr. Busk; and I have shown that it also occurs in *Selenaria maculata* ||; but when we go back to the Chalk we have in *Escharella argus*, d'Orb., a form which shows in a somewhat unexpected way the connection between *Onychocella* and *Cellaria*; for, in a specimen which I collected from Maastricht, there are teeth in the

* *Membranipora angulosa*, Rss., and *Melicerita dubia*, Busk.
† "Nouv. Div. des Bryoz. Cheil.," Bull. Soc. Zool. France, vol. vi. 1881.
‡ Journ. R. Microsc. Soc. ser. 2, vol. v. p. 106, fig. 42.
§ Ann. Mag. Nat. Hist. ser. 5, vol. iii. pl. xiii. fig. 3.
|| Suppl. 'Challenger' Report, p. 37.

aperture, both on the proximal and distal edge. Although the "onychocellaires" (vicarious avicularia) are not quite as simple, and a tongue projects into the avicularian opening, yet in the main they agree with those of *O. angulosa.* From general appearance we should not have imagined a connection between the now widely separated genera *Cellaria* and *Onychocella*; but, having obtained the key in these minute characters, we seem to find the connection in other species as well.

Koschinsky * has made a genus, *Rhagasostoma*, which, it would seem, should be considered a synonym. The clefts (Spalten) shown at the side of the oral aperture in Koschinsky's figures are more marked than in any specimens which I have examined, and usually in *O. angulosa* there is nothing of the kind; but it sometimes occurs, and is then caused by the greater development of the lower lip. The slits at the side of the oral aperture in *Aspidostoma* are filled by the operculum, but this is not here the case.

10. ONYCHOCELLA ANGULOSA (Reuss), (non d'Orb.).

(*a*) Incrusting.

*Cellepora angulosa*, Reuss, Foss. Polyp. des Wien. Tert. p. 93, pl. xi. fig. 10.

*Membranipora angulosa*, Reuss, Bryoz. von Crosaro, pp. 253, 262, 291, pl. xxix. figs. 9–11; Foram. Anth. u. Bryoz. von Oberburg, p. 30; Bryoz. Oest.-Ung. Mioc. p. 185 (45), pl. x. figs. 13, 14; Foss. Fauna d. Olig. von Gaas, p. 470; Manzoni, Brioz. di Castrocaro, p. 8, pl. i. fig. 11; Brioz. foss. Ital. pt. 4, p. 9, pl. ii. fig. 10; Waters, Ann. Mag. Nat. Hist. ser. 5, vol. iii. p. 122, pl. xiii. fig. 3; Pergens, Plioc. Bryoz. von Rhodes, p. 16.

*Membranipora antiqua*, Busk, Quart. Journ. Micr. Soc. vol. vi. p. 262, pl. xx. figs. 1, 2.

? *Mollia antiqua*, Smitt, Floridan Bryozoa, p. 12, pl. ii. fig. 73.

? *Membranipora hexagona*, Busk, Quart. Journ. Microsc. Soc. vol. iv. p. 308, pl. xii. fig. 4.

*Onychocella antiqua*, Jullien, Bull. Soc. Zool. de France, vol. vi. p. 9.

*Onychocella Marioni*, Jullien, *loc. cit.* p. 7, woodcut.

*Amphiblestrum angulosum*, Pergens, Bryoz. von Wola Lu'zanska, Bull. Soc. Belg. de Géol. vol. iii. p. 67.

? *Rhagasostoma hexagonum*, Koschinsky, Bryoz. ält. Tert. südl. Bayerns, p. 30, pl. v. figs. 5–7.

(*b*) In *Vincularia* stage, Pl. I. fig. 20.

*Eschara excavata*, Reuss, Foss. Polyp. Wien. Tert. p. 72, pl. viii. fig. 36.

*Biflustra excavata*, Manzoni, Brioz. foss. Mioc. d'Aust. ed Ung. p. 67, pl. xiii. fig. 44.

*Vincularia royana*, d'Orb. Pal. Fr. p. 108, pl. 602. figs. 12, 13, pl. 673. figs. 2, 3.

* Bryoz. ält. Tert. südl. Bayerns, p. 29.

*Eschara Lamarcki*, Hagenow, Bryoz. Maast. Kreide, p. 74, pl. ix. figs. 2, 3, 4.

*Vincularia geometrica*, Rss. Bryoz. von Crosaro, p. 276, pl. xxxiii. fig. 16.

*Periteichisma geometrica*, Koschinsky, Bryoz. ält. Tert. südl. Bayerns, p. 25.

*Vincularia disparilis*, Beissel, Bryoz. Aachener Kreide; Verh. Hollandsche Maat. d. Wetenschappen, pt. xxii. 1865, p. 15, pl. i. figs. 7, 8.

Comparative measurements of the zoœcia show no difference between the incrusting form called *angulosa*, and the erect form named *excavata*; and Reuss (Bryoz. von Crosaro, p. 79) refers to *M. angulosa* in the *Biflustra*-stage.

From Brendola and the other localities there are many specimens which are at first incrusting, and then free in the *geometrica*-form; but the almost cylindrical *M. excavata* passes by gradations into compressed *Biflustra*-like forms. The *M. sexangularis*, Goldf., of the Maastricht Chalk is of about the same size, and at one time I was inclined to unite them; but the surface of the zoœcium is almost flat in *sexangularis* instead of depressed, and the zoœcia being proportionally shorter, there results a more regular hexagonal appearance.

Probably, besides the above synonyms, many others should be added, as *Vincularia excavata*, d'Orb. *loc. cit.* p. 69; *V. santonensis*, d'Orb., p. 73; *V. leda*, d'Orb., p. 88; *Eschara acmon*, d'Orb., p. 115; *E. allica*, d'Orb., p. 125; *E. arcas*, d'Orb., p. 127; *E. actæa*, d'Orb., p. 116; *E. arethusa*, d'Orb., p. 127.

*Loc.* Cretaceous: Maastricht; Royan, &c. Lower Tertiary: Val di Lonte; Brendola; Montecchio Maggiore; Crosaro; Priabona; Novezzina; Malo; Oberburg; Gaas; Nussdorf, near Vienna (*Manz.*); Götzreuth; Wola Lu'zanska; Dego; Turin, &c. Pliocene: Italy; Sicily; Rhodes. Living: Mediterranean; Madeira; Ile de France; Florida (?).

### Vibracella, gen. nov.

The *Flustrellaria trapezoidea* of Reuss is an extremely interesting form, as in respect of the zoœcia it seems connected with *Onychocella*; but, instead of the vicarious avicularia, there are cells scattered among the zoœcia, which I should call vicarious vibracular cells. The beak-like prolongation is wanting, and instead one side of the vicarious cell is very much raised, indicating a vibracular appendage, similar to that of *Cupularia*, in which genus the one side is in the same way usually "auriform." The *F. trapezoidea* cannot, on account of these vibracula, be placed with *Onychocella*, as at present defined; to leave it with *Membranipora* after removing *Onychocella* could only be a provisional arrangement; and *Flustrellaria* was made to include free-growing forms of the *Onychocella* type; so that, although reluctant to do so, until we know more of its allies, I propose the genus *Vibracella* for forms in which the zoœcia have moderately large opesial openings, and in which there

are vicarious eared vibracular cells. The only species is *V. trapezoidea* (Reuss).

11. Vibracella trapezoidea (Reuss). (Pl. I. fig. 23.)

*Cellepora trapezoidea*, Reuss, Foss. Polyp. Wien. Tert. p. 96, pl. xi. fig. 21.

*Flustrellaria trapezoidea*, Reuss, Bryoz. von Crosaro, p. 268, pl. xxix. fig. 14.

The most important points have been dealt with when describing the genus.

As a rule, the zoarium is discoid or conical, but from some specimens it would seem to sometimes grow in larger flat pieces. Reuss, in his first description, says "incrusting;" but in his second he figures and describes it as free. One specimen from Brendola is incrusting, but all the others are free.

*Selenaria miocœnica*, Seguenza, may be this or *Onychocella angulosa*; also *Flustrellaria hexagona*, d'Orb., from the Senonian, seems very closely allied; but in the absence of vibracula or avicularia it is in both cases impossible to say whether they are identical.

*Loc.* Val di Lonte (*Reuss* and my collection); Brendola; Montecchio Maggiore; Bocca di Sciesa; Ferrara di Monte Baldo; Malo.

12. Membranipora macrostoma (Reuss).

*Cellaria macrostoma*, Reuss, Foss. Polyp. Wien. Tert. p. 64, pl. viii. figs. 5, 6.

*Biflustra macrostoma*, Reuss, Bryoz. von Crosaro, p. 274, pl. xxxiii. figs. 12, 13.

*Flustrellaria macrostoma*, Manzoni, Brioz. foss. Mioc. d'Aust. ed Ung. p. 67, pl. xiii. fig. 46.

? *Membranipora macrostoma*, Waters, Quart. Journ. Geol. Soc. vol. xxxvii. p. 323, pl. xiv. figs. 18, 19; Koschinsky, Bryoz. ält. Tert. südl. Bayerns, p. 22.

*Vaginopora texturata*, Reuss, Foss. Polyp. Wien. Tert. p. 73, pl. ix. fig. 1.

*Flustrellaria texturata*, Reuss, Foss. Fauna von Wieliczka, p. 119; Manzoni, Brioz. foss. Mioc. d'Aust. ed Ung. p. 67, pl. xiii. fig. 45.

*Biflustra papillata*, Stoliczka, Foss. Bryoz. Orakei Bai, p. 154, pl. xx. fig. 14.

From Brendola there is a fragment of *M. concatenata*, Rss., either in a single free layer or with two layers back to back; and, as pointed out by Koschinsky, the zoœcia are the same as those of *M. macrostoma*, both in shape and size. There are also some fragments with squarer zoœcia, which should perhaps be called *M. Savartii*, Aud.

*Loc.* Val di Lonte; Montecchio Maggiore; Brendola; Ferrara di Monte Baldo; Ronzo; Nussdorf, &c. (*Manz.*); Wieliczka (*Rss.*); Götzreuth (*Kosch.*).

13. Membranipora tenuirostris, Hincks.

*Membranipora tenuirostris*, Hincks, Ann. Mag. Nat. Hist. ser. 5,

vol. vi. p. 70, pl. ix. fig. 3; *op. cit.* vol. x. p. 7; Waters, Journ. R. Microsc. Soc. ser. 2, vol. v. p. 755, pl. xiv. fig. 41.

*Membranipora Flemingii*, Waters, Ann. Mag. Nat. Hist. ser. 5, vol. iii. p. 122, pl. xiii. fig. 2.

*Loc.* Living: Mediterranean; Madeira; Queen Charlotte Island. Fossil: Val di Lonte; Montecchio Maggiore.

14. Membranipora Dumerilii (Aud.). (Pl. II. fig. 4.)

For synonyms, see Hincks, Brit. Mar. Polyz. p. 156.

*Membranipora Dumerilii*, Koschinsky, Bryoz. ält. Tert. südl. Bayerns, p. 21.

*Membranipora bicornis*, Manzoni, Form. Terz. di Reggio, p. 80, pl. viii. fig. 10.

The Vicentine specimens may be taken as fairly typical, *M. Dumerilii* having two avicularia above the ovicell, and zooecia without an ovicell, having either one or two avicularia. This is very similar in shape to *M. appendiculata*, but is much smaller, the opesia being only about 0·35 millim. long. I described a fossil from New Zealand (Quart. Journ. Geol. Soc. vol. xliii. p. 45) as *M. Dumerilii*, although somewhat divergent from the type.

*Loc.* Living: European Seas. Fossil: Crag; Pliocene of Calabria; Waipukerau, New Zealand (?); Brendola; Montecchio Maggiore; Val di Lonte; Götzreuth (*Kosch.*).

15. Membranipora Rosselii (Aud.). (Pl. II. figs. 1, 2.)

*Flustra Rosselii*, Audouin, in Savigny's 'Egypte,' p. 240, pl. x. fig. 11.

*Membranipora Rosselii*, Waters, Ann. Mag. Nat. Hist. ser. 5, vol. iii. p. 121; Hincks, Brit. Mar. Polyz. p. 166, pl. xxii. fig. 4 (which work see for synonyms).

*Cellepora deplanata*, Reuss, Foss. Polyp. Wien. Tert. p. 96, pl. xi. fig. 20.

*Membranipora deplanata*, Reuss, Bryoz. von Crosaro, p. 263, pl. xxix. fig. 12.

*Periteichisma deplanatum*, Koschinsky, Foss. Bryoz. südl. Bayerns, p. 26.

A colony from Brendola has a slightly raised small hood-like ovicell. There are a few zooecia (fig. 1 *a*) nearly double the width of ordinary zooecia, and they cannot be considered ovicelligerous, seeing that there are ovicells; but perhaps irregularities on the surface on which they are growing has caused this difference in size. There are, besides, in some specimens raised giant zooecia, occupying about the space of three zooecia. As the living *M. Rosselii* is pretty regular, perhaps we should call this var. *deplanata*.

*Loc.* Living: Britain; Mediterranean. Fossil: Pliocene of Italy and Sicily; Miocene of Vienna Basin; Val di Lonte; Montecchio Maggiore; Brendola; Götzreuth (*Kosch.*).

16. Membranipora patellaria (Moll).

*Eschara patellaria*, Moll, Die Seerinde, p. 75, pl. iv. fig. 20.
*Diachoris simplex*, Heller, Bryoz. Adriat. Meeres; Verh. k. k. zool.-Bot. Gesellsch. vol. xvii. 1867, p. 94, pl. i. fig. 4.
*Mollia patellaria*, Smitt, Floridan Bryoz. p. 12, pl. ii. fig. 72.
*Diachoris patellaria*, Waters, Ann. Mag. Nat. Hist. ser. 5, vol. iii. p. 120, pl. x. figs. 6–9.

The fossil from Montecchio Maggiore is a very typical *M. patellaria*, with six connecting-tubes.

*Loc.* Living: Naples; Florida. Fossil: Montecchio Maggiore.

17. Membranipora appendiculata (Reuss). (Pl. II. fig. 3.)

*Cellepora appendiculata*, Reuss, Polyp. Wien. Tert. p. 96, pl. xi. fig. 22.
*Membranipora appendiculata*, Reuss, Fauna deutsch. Oberoligoc. p. 631, pl. ix. fig. 4; Oest.-Ung. Mioc. p. 181, pl. ix. figs. 13–16; Foram. Anth. Bryoz. Septarienthones, p. 171; Waters, Quart. Journ. Geol. Soc. vol. xxxviii. p. 504, pl. xxii. figs. 2–5; Seguenza, Form. Terz. Prov. di Reggio, Accad. dei Lincei, vol. cclxxvii. p. 80; Koschinsky, Bryoz. ält. Tert. südl. Bayerns, p. 23.
*Membranipora cyclops*, Busk, Catal. Mar. Polyz. p. 61, pl. lxv. fig. 3.
*Membranipora monopora*, Reuss, Bryoz. von Crosaro, p. 262, pl. xxix. fig. 7.

A specimen from Montecchio Maggiore has wide (0·5 millim.) oval opesia, below which there is a single raised avicularium placed laterally. The determination of simple *Membraniporæ* is seldom very satisfactory, and in the present case it is doubtful whether this is not the same as *M. rhynchota*, Busk.

*Loc.* Brendola; Val di Lonte (*Rss.*): Montecchio Maggiore.

18. Membranipora Hookeri, Haime.

*Membranipora Hookeri*, Reuss, Bryoz. von Crosaro, p. 252, pl. xxix. figs. 6, 8, and my coll.

The opesia are about 0·35 millim. long and 0·2 millim. wide.

*Loc.* Crosaro (*Rss.*); Val di Lonte (*Rss.*); Montecchio Maggiore (*Rss.*); India (*Haime*).

19. Micropora coriacea (Esper). (Pl. II. fig. 9.)

*Micropora coriacea*, Hincks, Brit. Mar. Polyz. p. 174 (which see for synonyms).
*Membranipora gracilis*, Reuss, Bryoz. von Crosaro, p. 291, pl. xxix. fig. 13.

Besides those specimens with elliptical zoœcia, there is one from Val di Lonte with the sides parallel, and this I suppose must also be united with the *M. gracilis* (von Münster).

*Loc.* Living: Britain; Florida; Azores. Fossil: Brendola; Montecchio Maggiore; Val di Lonte; Pliocene of Calabria (*Manz.*).

20. Micropora polysticha (Reuss). (Pl. II. fig. 7.)

*Cellaria polysticha*, Reuss, Foss. Polyp. Wien. Tert. p. 61, pl. vii. fig. 33.

*Eschara polysticha*, Reuss, Bryoz. von Crosaro, p. 269, pl. xxxii. fig. 3.

? *Steganoporella similis*, Koschinsky, Bryoz. ält. Tert. südl. Bayerns, p. 34, pl. i. figs. 8–10.

The zoaria vary considerably in the number of rows of zoœcia. The zoœcia are elongate, and about the same size and shape as those of *Micropora parallela*, but differ from that species in the absence of avicularia and in having opesiules. The opesiules in some parts are not apparent, and in different specimens vary in position, occurring sometimes about the middle of the zoœcium, but more usually only about one quarter of the way down.

Although the zoœcia of *Steganoporella similis*, K., are a trifle larger, the characters are similar, and probably they should be united.

*Loc.* Val di Lonte (*Rss.*); Brendola; Ferrara di Monte Baldo; Montecchio Maggiore; Götzreuth (*Kosch.*).

21. Micropora parallela (Reuss). (Pl. II. fig. 8.)

*Eschara parallela*, Reuss, Bryoz. von Crosaro, p. 272, pl. xxxiii. fig. 2.

When properly cleaned a small triangular avicularium near the oral aperture, directed downwards, is distinctly seen. Ovicell not much raised, wider than a zoœcium; apparently there has been an area on the front. When sections are being made, the shell just above the avicularium is seen to be thinner than the surrounding parts, often giving the appearance of a peristomial notch, and this can also be seen in some specimens without preparation. Zoœcia at the side of the zoarium alternate.

The avicularia were overlooked by Reuss, and since they do not occur on all zoœcia, and may be covered by the matrix, it often appears as if there was only a pore, as described by Reuss; and Pergens, thinking this was the case, has made the genus *Houzeauina* for a fossil which he considered the same as the *E. parallela* of Reuss. This is probably not identical with the Vicentine fossils, as M. Pergens writes that the hole was "complet," and that there was no avicularian chamber; and no doubt I may be allowed to say that, after seeing a specimen from my collection, he agrees with my view.

*Loc.* Val di Lonte; Brendola; Montecchio Maggiore; Crosaro; Novezzina.

22. Micropora articulata, sp. nov. (Pl. II. figs. 5, 6.)

Specimens from Montecchio Maggiore are about the same size as the recent *M. ratoniensis* *, Waters, from New Guinea. Although

* It should have been *katowensis*, but the name of the locality was read Raton, and there does not now seem any reason to change it. Mr. Whitelegge informs me that he has found it recent from Singapore.

the zoœcia are not always arranged quite as diagonally as in that recent form, yet the diagonal arrangement is usually seen. The fossil differs from the recent species in the shape of the "special organs," which, instead of being a small triangular avicularium placed diagonally, seems to have been a vibraculum; at any rate, below the zoœcial area there is an eminence with two almost equal pores in the line of the zoarial axis.

There is a suboral slit on one side only of the area. The zoœcia are usually arranged on the four sides of the axis; but in one case they are only on two sides, in this respect resembling *Diplodidymia complicata*, Rss., from the "Oligocän" of Gaas, and the *Cellularia diplodidymoides* of Meunier and Pergens from the Chalk. We have thus four closely allied forms, with similar-shaped zoœcia, placed diagonally, with a long suboral slit on one side and a special organ below the aperture.

23. Micropora cucullata (Reuss).

*Cellaria cucullata*, Reuss, Foss. Polyp. Wien. Tert. p. 60, pl. vii. fig. 31.

*Vincularia cucullata*, Manzoni, Brioz. foss. Mioc. d'Austr. ed Ung. p. 69, pl. xv. fig. 50, pl. xvi. fig. 53.

*Eschara costata*, Reuss, *loc. cit.* p. 72, pl. viii. fig. 37.

*Eschara Reussi*, Stoliczka, Olig. Bryoz. von Latdorf, p. 88; Reuss, Fauna des deutschen Oberoligocäns, p. 36.

*Vincularia Haidingeri*, Reuss, Bryoz. von Crosaro, p. 275, pl. xxxiii. figs. 14, 15.

*Biflustra sulcata*, Gottardi, Brioz. foss. di Montecchio Maggiore; Atti d. Soc. Veneto-Trentina di Sc. Nat. vol. ix. fasc. ii. p. 305, pl. xiv. fig. 2.

*Steganoporella elegans*, Koschinsky, Bryoz. ält. Tert. südl. Bayerns, p. 33.

? *Eschara elegans*, M.-Edw. Ann. Sc. Nat. sér. 2, vol. vi. p. (17) 337, pl. xii. fig. 13.

*Micropora cucullata*, Pergens, Bryoz. von Wola Lu'zanska, p. 67.

*Salicornaria* (*Cellaria*) *cucullata*, Gioli, Brioz. Neogenici dell' Isola di Pianosa; Atti Soc. Tosc. Sc. Nat. vol. x. p. (10).

Besides the erect zoaria in the *Vincularia*-form, there are incrusting specimens from both Val di Lonte and Brendola. In the erect and incrusting zoaria the ordinary zoœcia are similar in size and shape; but the zoœcia which we conclude are ovicelligerous are somewhat larger and wider in the incrusting specimens; perhaps, however, this is to be accounted for by the conditions of growth. The large zoœcia have a large shelf above the aperture. The proximal edge in the ordinary zoœcia is much thinner than the distal border, but is continuous, so that the appearance is entirely that of *Micropora*; on the other hand, the broad ovicellular cells are like those of recent *Steganoporella magnilabris*, and I am unable to find grounds for separating these two genera.

A specimen of *Eschara Egæa*, d'Orb., from Royan has similar larger ovicelligerous cells.

*Loc.* Several Miocene localities in Austria and Hungary. Val di Lonte; Brendola; Montecchio Maggiore; Ferrara di Monte Baldo; Ronzo; Crosaro; Priabona; Malo; Götzreuth (*Kosch.*), Latdorf; Wola Lu'zanska; Astrupp (Miocene), Pianosa (Miocene).

24. Cribrilina radiata (Moll).

There is considerable variation in the appearance of various specimens, caused by difference in the number of costæ; and in some cases vicarious avicularia are present; also some specimens from Val di Lonte and Brendola have the lower lip somewhat raised, and at each side of the aperture there is a small avicularian or vibracular opening, giving the appearance of *C. puncturata* of Busk.

The pores between the costæ are more numerous than in *C. Haueri*, Reuss, though, when crushed, they look like Reuss's figure 16, pl. xxxii., which he calls *E. Haueri*, but I have only seen this shape of zoœcia in incrusting forms; and stems of other Bryozoa are often so completely covered that without careful examination they might be taken for erect specimens.

*Loc.* Living: Cosmopolitan. Fossil: Val di Lonte; Brendola; Montecchio Maggiore; Novezzina; Söllingen; Wola Lu'zanska; various Austrian and Hungarian Miocene localities. Pliocene: Crag; Italy; Sicily; and Rhodes. Recent, Australia.

25. Cribrilina chelys, Koschinsky. (Pl. II. fig. 10.)

*Celleporaria radiata*, Reuss (*non* Moll), Bryoz. von Crosaro, p. 292, pl. xxx. fig. 9.

*Cribrilina chelys*, Koschinsky (nom. nov.), Bryoz. ält. Tert. südl. Bayerns, p. 36; Pergens, Bryoz. von Wola Lu'zanska, p. 70.

There is a large oval avicularium at one or both sides of the zoœcium, and the large pores around the area are irregularly placed. What Reuss described as the large pore above the aperture is an avicularium, that of one zoœcium often being situated above the aperture of its neighbour. There are also a few very large vicarious avicularia. The ovicell is very large, but slightly raised, and has an irregularly perforated area on the front, and reminds us of the ovicell of *Lepralia occlusa*, B. The ovicell and vicarious avicularium are added to fig. 10 from different parts of the colony. There is considerable difference in the appearance of various parts of the colony, as in some parts the avicularia are very numerous, but elsewhere absent, and there are sometimes irregular pores at the side of the zoœcium; but in no case have I seen the regularity figured by Reuss, and probably a worn specimen was examined, and then the artist used his imagination. I have specimens incrusting other objects in a single layer; but, as a rule, there are several layers superimposed.

*Loc.* Priabona (*Rss.*); Brendola; Val di Lonte; Grancona; Götzreuth (*Kosch.*); Wola Lu'zanska (*Perg.*).

26. Cribrilina crenatimargo (Reuss).

*Cellaria Haueri*, Reuss, Foss. Polyp. Wien. p. 63, pl. viii. fig. 9.
*Eschara crenatimargo*, Reuss, *op. cit.* p. 72, pl. viii. fig. 38.
*Cribrilina crenatimargo*, Pergens, Bryoz. von Wola Lu'zanska, p. 69.
*Eschara Haueri*, Reuss, Bryoz. von Crosaro, p. 271, pl. xxxii. figs. 14–16.

The zoœcial characters are very similar to those of *C. radiata*, Moll, but the zoœcia are more elongate, the costæ are nodulated, and the number of pores between the costæ is fewer than in the fossil *C. radiata*. The front is often depressed, as shown by Reuss, *op. cit.* pl. xxxii. fig. 15; but this seems to arise from the front wall being thin and pressed in. The erect form of *Cribrilina* is unknown living; but it is possible that this should be looked upon as erect *C. radiata*, Moll.

The specific name *Haueri* has been given to another *Cribrilina*, the *Lepralia Haueri*, Rss. (Bryoz. Oest.-Ung. Mioc. p. 170, pl. i. figs. 1, 2), and it therefore seems better to drop the name *Haueri*.

*Loc.* Val di Lonte; Brendola; Montecchio Maggiore; Ferrara di Monte Baldo; Malo; Wola Lu'zanska (*Pergens*); Pap-Patak, Hungary (*Perg.*); Siebenbürgen (*Perg.*).

27. Monoporella sparsipora (Reuss). (Pl. II. fig. 11.)

*Lepralia sparsipora*, Reuss, Bryoz. von Crosaro, p. 263, pl. xxx. fig. 1.
*Homalostega exsculpta*, Marsson, Die Bryoz. der weiss. Schreibkreide der Insel Rügen, p. 95, pl. x. fig. 2.

From Val di Lonte this occurs both in an incrusting and in a compressed *Eschara*-form; from Montecchio Maggiore it is in the *Eschara*-form, and from Brendola it is incrusting. Ovicells plain, very wide, globose, moderately raised. *Lepralia nuda*, Reuss (Oest.-Ung. Mioc. p. 33), appears closely related.

*Loc.* Priabona (*R.*); Val di Lonte; Brendola; Montecchio Maggiore; Ferrara di Monte Baldo; Malo; Rügen (Cretaceous, *Marsson*).

28. Lepralia subchartacea (d'Arch.). (Pl. II. fig. 12.)

*Eschara subchartacea*, d'Arch. Mém. Soc. Géol. France, sér. 2, vol. iii. p. 410, pl. ix. fig. 2; Reuss, Bryoz. von Crosaro, p. 269, pl. xxxii. fig. 4.
*Eschara chartacea*, d'Arch. *op. cit.* vol. ii. p. 196, pl. v. fig. 13.
*Cellaria stenosticha*, Reuss, Foss. Polyp. Wien. Tert. p. 64, pl. viii. fig. 10.
*Eschara stenosticha*, Reuss, Bryoz. von Crosaro, p. 269, pl. xxxii. fig. 2.

The thin compressed form described by Reuss as *subchartacea* is fairly common in Brendola, but not in the other localities; and to some zoœcia there is a small avicularium within the depression for the oral aperture, and also there is sometimes an avicularium on the middle of the zoœcium. The branches spread out in a somewhat fan-shaped manner, at first being about 2 millim. wide, and

expanding to about 10 millim. The cylindrical form, which may be also with or without avicularia, is less common, and was described as *E. stenosticha*. Lateral teeth are seen within the oral aperture. Zoœcia at the side alternate.

*Loc.* Val di Lonte and Pyrenees (*Rss.*); Brendola; Montecchio Maggiore; Pap-Falvi-Patak, Hungary (*Perg.*).

29. Lepralia semilævis (Reuss).

*Eschara semilævis,* Reuss, Bryoz. von Crosaro, p. 270, pl. xxxii. figs. 7, 8.

*Eschara larva,* Reuss, Foss. Polyp. Wien. Tert. p. 69, pl. viii. fig. 29; Pergens, Bryoz. von Wola Lu'zanska, p. 70.

*Eschara Suessi,* Reuss, Bryoz. von Crosaro, p. 270, pl. xxxii. fig. 9; Pergens, *op. cit.* p. 70.

*Eschara intermedia,* Gottardi, Brioz. foss. di Montecchio Maggiore; Atti della Soc. Veneto-Trentina di Sc. Nat. vol. ix. p. 307, pl. xiv. fig. 6.

At the side of the aperture there is usually on one or both sides a narrow spatulate avicularium, placed either slightly diagonal or directed straight upwards. The characteristic avicularia and ovicells occur in specimens both with the zoarial growth of *semilævis* and *Suessi*, showing that Reuss was right in thinking that these two might be only varieties of growth. In one specimen the bases of five spines round the aperture are very distinct, the lower two being the largest, and these two are figured by Gottardi in his *E. intermedia.*

The zoœcia seen at the side of the colony are alternate.

*Loc.* Val di Lonte (*Rss. & Waters*); Brendola; Montecchio Maggiore; Priabona; Novezzina; Ronzo; Wola Lu'zanska in Galicia (*Perg.*); several localities in Hungary (*Perg.*).

30. Lepralia bisulca (Reuss). (Pl. II. figs. 16–18, & Pl. III. fig. 1.)

*Eschara bisulca,* Reuss, Bryoz. von Crosaro, p. 270, pl. xxxii. fig. 10.

? *Schizoporella bisulca,* Koschinsky, Bryoz. ält. Tert. südl. Bayerns, p. 49.

*Eschara microdonta,* Reuss, *op. cit.* p. 271, pl. xxxii. fig. 13.

*Eschara fenestrata,* Reuss, *op. cit.* p. 290, pl. xxxii. fig. 5.

This is an extremely interesting form on account of the great difference in shape between the ordinary and ovicelligerous zoœcia. In the aperture there is usually an avicularium; and in this respect, and also in the elevation at the side of the aperture, it resembles *Smittia* (*Porella*) *cervicornis.* Sometimes this avicularium takes a spatulate form, and may be depressed (as in Pl. II. fig. 17), or may be much elevated (fig. 16). In many other species, in the same way, a small oral avicularium is sometimes replaced by a large spatulate one, as for instance in *Schizoporella auriculata* and *Porella cervicornis,* &c. Occasionally, instead of the elevation at the side of the aperture, two teeth are formed within it (Pl. III. fig. 1).

The ovicelligerous zoœcia, instead of being parallel with the axis of the zoarium, turn at right angles to it, and are much raised in their distal end, with the ovicell somewhat recumbent behind the peristome. In the form of the aperture and the ovicells this is closely related to *L. nodulifera* (Rss.). Pl. II. fig. 16 is the *L.-microdonta*-form, with the row of fine linear pores round the border, and the separating ridges running in to the aperture, with the avicularia and ovicells resembling those of more typical *L. bisulca*.

I do not feel at all sure from the description that Koschinsky had the same thing before him.

*Loc.* Val di Lonte and Montecchio Maggiore (*Rss. & Waters*); Brendola (*Waters*); Ferrara di Monte Baldo (*W.*); Novezzina; Malo; Ronzo (*W.*); Crosaro (*W.*); Götzreuth ? (*Kosch.*); several Hungarian localities (*Perg.*).

31. Lepralia nodulifera (Reuss). (Pl. II. figs. 13, 14.)

*Eschara nodulifera*, Reuss, Bryoz. von Crosaro, p. 271, pl. xxxii. figs. 11, 12.

*Periteichisma noduliferum*, Koschinsky, Foss. Bryoz. ält. Tert. südl. Bayerns, p. 27.

*Amphiblestrum noduliferum*, Pergens, Bryoz. von Wola Lu'zanska, p. 67.

The aperture is slightly rounded below, and sometimes the thick calcareous growth of the divisional walls extends round the aperture, but sometimes it only occurs above the aperture. In some cells the proximal end is raised, and in one colony there are ovicells behind the aperture of such zoœcia. In one case there seems to be a raised avicularium at the border of the zoœcium, but I cannot speak with certainty about it.

This seems to have nothing in common with the other *Periteichismæ* of Koschinsky; and the genus appears based on the nature of the calcification rather than upon characters of much value; in fact some have an opesial opening, but in others, as in *nodulifera*, the aperture has, no doubt, been closed by an operculum.

*Loc.* Val di Lonte and Montecchio Maggiore (*Rss.*); Brendola (*Waters*); Ferrara di Monte Baldo (*W.*); Ronzo (*W.*); Priabona; Götzreuth (*Kosch.*); Wola Lu'zanska (*Perg.*).

32. Lepralia impressa (Reuss). (Pl. II. fig. 15.)

*Vincularia impressa*, Reuss, Bryoz. von Crosaro, p. 276, pl. xxxiv. fig. 2.

*Amphiblestrum impressum*, Pergens, Bryoz. von Wola Lu'zanska, p. 67.

On a specimen from Brendola there is a raised round ovicell above the aperture, perforated with pores somewhat more crowded than those on the front of the zoœcium. In some cases there is an avicularium at one side below the aperture, and then it looks like an early stage of *Cellepora proteiformis*, Rss.

*Loc.* Val di Lonte; Brendola; Wola Lu'zanska (*Perg.*).

33. Lepralia excentrica, Reuss.

*Lepralia excentrica*, Reuss, Fauna deutsch. Oberoligoc. p. 28, pl. xv. fig. 4; Fauna des Septarienthones, p. 175, pl. viii. fig. 2; Bryoz. von Crosaro, p. 256.

? *Cumulipora angulata*, Reuss, Fauna des Septarienthones, p. 179, pl. viii. fig. 12.

A cylindrical zoarium from Montecchio Maggiore, with the zoœcia distinct, with broad radial grooves round the border, and a raised suboral pore, would seem to be the *L. excentrica* of Reuss; but so many species have been described with similar zoœcia that no doubt there are many synonyms. The specimen from Montecchio Maggiore has large spatulate vicarious avicularia.

*Loc.* Söllingen; Oberoligocän of Doberg; Crosaro (*Rss.*); Montecchio Maggiore.

34. Lepralia (?) syringopora (Reuss). (Pl. III. figs. 2, 3, 4.)

*Eschara syringopora*, Reuss, Foss. Polyp. Wien. Tert. p. 68, pl. viii. fig. 23; Bryoz. von Crosaro, p. 269, pl. xxxii. fig. 1.

*Schizoporella perspicua*, Koschinsky, Bryoz. ält. Tert. südl. Bayerns, p. 49, pl. iv. fig. 3.

? *Eschara minor*, Reuss, Bryoz. von Crosaro, p. 272, pl. xxxiii. fig. 4.

? *Eschara polystomella*, Reuss (*non* Manz.), Foss. Polyp. p. 70, pl. viii. fig. 28.

? *Eschara semitubulosa*, Reuss, Bryoz. von Crosaro, p. 272, pl. xxxiii. fig. 3.

This is an extremely interesting species on account of the peculiar bar across the aperture.

Zoarium in the *Eschara*-form; branches small, compressed, with the zoœcia of the two layers opposite. Zoœcia elongate, the upper end slightly projecting, and a row of large pores down each side of the zoœcium. In the central cells these rows are near together, but in the outer zoœcia there is a considerable space between them. About the middle of the oral aperture on each side there is a pore, and in many cases a bar across, as figured by Stoliczka in his *Escharifora ornatissima* (Bryoz. von Latdorf, p. 86, pl. ii. fig. 7), but the shape of the zoœcia in that species is hexagonal.

Reuss in his second paper figures his *E. syringopora* with the oral pores lower than the aperture; and sometimes when the aperture is somewhat broken down it has this appearance.

There are sometimes also other large pores on various parts of the surface, usually one about halfway down, and these may be avicularian.

In some specimens there are "closures" over the aperture, and these have a tubule in the centre similar to those of so many *Diastoporæ*, &c. This is at a higher level than the operculum.

It is abundant at all the stations.

*Loc.* Val di Lonte and Montecchio Maggiore (*Rss.*); Brendola;

Ferrara di Monte Baldo; Ronzo; Priabona (*Kosch. & W.*); Götzreuth (*Kosch.*); Malo.

35. Lepralia (?) bericensis, sp. nov. (Pl. III. fig. 18.)

From Bocca di Sciesa, Colle Berici, there are specimens with *Cupularia*-growth, the disks measuring 10–15 millim. in diameter. The zoœcia are ovoid to hexagonal, separated by a distinct ridge, with a row of large pores round the border; and in a few zoœcia there is a small avicularium at one or both sides of the aperture. The oral aperture is rounded on the distal edge, and the proximal border curves inwards, reminding us of the aperture of *Lepralia castanea*, Busk.

36. Lepralia (?) lontensis, sp. nov. (Pl. III. fig. 5.)

Zoarium very thin and delicate, with the zoœcia at the side of the colony opposite. Zoœcia long, bordered by a row of pores, with the peristome projecting in a tubular form, within the wall of which there is on one side a small tube, which may be avicularian, and reminds us of the avicularian tube of a group of *Celleporæ* represented by *C. granum*, H.

I am unable to identify this with any of Reuss's species, though, as it is abundant, it must have come into his hands. At first, I thought it was his *semitubulosa*. It also looks very much like the *Eschara syringopora* of Reuss in Foss. Polyp. Wien. Tert. pl. viii. fig. 3; and it seems somewhat doubtful whether he then had the *E. syringopora* of his later paper before him. *Eschara fistulosa*, Rss., in the same paper may be this species.

*Loc.* Val di Lonte; Montecchio Maggiore; Brendola; Ronzo; Ferrara di Monte Baldo; Crosaro; Malo.

37. Smittia coccinea (Abild.). (Pl. III. fig. 8.)

Several incrusting specimens from Brendola and Montecchio Maggiore show great range in the size of the avicularia; some having a small one at each side, while others have them directed forwards as in fig. 8.

Widely distributed, both living and fossil.

38. Smittia coccinea (Abild.), var. alifera (Reuss). (Pl. III. fig. 7.)

*Eschara alifera*, Reuss, Bryoz. von Crosaro, p. 274, pl. xxxiii fig. 11.

*Mucronella alifera*, Pergens, Bryoz. von Wola Lu'zanska, p. 71.

The branches from Brendola are pretty uniform in breadth, but those from Val di Lonte are irregular in size. The pores round the borders of the zoœcia are much more distinct than is usually the case in *M. coccinea*, although they occur in living forms. In most zoœcia there is an avicularium at each side, but in others there is only one, and there is considerable difference in size and direction. Ovicell usually very much immersed, sometimes more exposed and recumbent.

In the size of the zoœcia the living and Eocene forms agree, and

the incrusting *Mucronella loricata* of Koschinsky and *M. præstans*, H., are closely allied. It is considered a variety of *S. coccinea* on account of its erect growth, and may be said to be *S. coccinea* in the *Eschara*-form; but it is *Mucronella* for those who retain that genus.

*Loc.* Val di Lonte; Brendola; Montecchio Maggiore; several localities in Hungary (*Pergens*); Wola Lu'zanska (*Pergens*); Ferrara di Monte Baldo; Ronzo; Malo.

39. Smittia Landsborovii (Johnst.), var. Cheilopora, Rss. (Pl. III. fig. 12.)

*Cellepora cheilopora*, Reuss, Polyp. Wien. Tert. p. 91, pl. xi. fig. 4.

*Lepralia cheilopora*, Reuss, Foss. Bryoz. Oest.-Ung. Mioc. p. 168, pl. iv. fig. 1.

Peristome considerably raised, and within the aperture a projecting avicularium. There are pores around the border of the zoœcium, and on the round raised ovicells there are also a few large pores.

This seems closely allied to the recent form from New South Wales which I described (Ann. Mag. Nat. Hist. ser. 6, vol. iv. p. 16, pl. iii. figs. 14 and 15) as *S. malleolus*, and both are about the same size, but the recent form is punctured over the surface.

*Loc.* Satschan (Moravia); Brendola.

40. Smittia porrigens (Reuss). (Pl. III. fig. 9.)

*Lepralia porrigens*, Reuss, Foram. Anth. und Bryoz. des Septarienthones, p. 175, pl. vii. fig. 15.

There are incrusting specimens from Montecchio Maggiore and Brendola, which are probably the *S. porrigens* of Reuss, but have perhaps received various other names. It has a wide lyrula plate in the aperture and a round suboral avicularium; pores round the border of the zoœcia very indistinct; ovicell globular, recumbent or partly immersed, and punctured.

Probably this is *Lepralia Seguenzai*, Reuss (Bryoz. von Crosaro, p. 254, pl. xxxvi. fig. 11).

*Loc.* Söllingen; Montecchio Maggiore; Brendola.

41. Smittia exarata (Reuss). (Pl. III. fig. 6.)

*Cellaria exarata*, Reuss, Foss. Polyp. Wien. Tert. p. 61, pl. vii. fig. 32.

*Vincularia exarata*, Reuss, Bryoz. von Crosaro, p. 276, pl. xxxiv. fig. 1.

The zoœcia are slightly rounded, and there is a row of pores close to the border. The oral aperture is at some distance from the surface, and I have been able to make out a wide denticle within it; but the proximal edge of the peristomatal aperture also bends inwards, and might be called a mucro. The ovicells are short and usually considerably immersed. This may be allied to *Bracebridgia geometrica* (Rss.).

*Loc.* Val di Lonte (*Rss. & Waters*); Montecchio Maggiore; Brendola; Ferrara di Monte Baldo.

42. Porella imbricata (Reuss). (Pl. III. figs. 16, 17.)

*Eschara imbricata*, Reuss. Foss. Polyp. Wien. Tert. p. 69, pl. viii. fig. 26.

Zoarium incrusting; but, when completely covering the branch of some other species, it at first appears to be free. In my specimens it is difficult to see the structure of the younger zoœcia; but the proximal edge is straight, with a small central avicularium within the aperture; this, however, is not visible in the older zoœcia. In the older zoœcia the transverse shape of the aperture is very curious and often triangular, caused by an infolding of the proximal edge. The pores round the border are readily distinguished in some zoœcia, but not in all. Ovicell recumbent, distinct, not much raised, punctured.

Fig. 16 represents a rather abnormal zoœcium, in which there are large pores at the border.

*Loc.* Val di Lonte (*Rss. & Waters*); Brendola; Montecchio Maggiore.

43. Porella marsupium, MacG., var. porifera, Hincks. (Pl. III. fig. 13.)

*Porella marsupium*, MacG., var. *porifera*, Hincks, Ann. Mag. Nat. Hist. ser. 5, vol. xiii. p. 24, pl. iv. fig. 4; Waters, Quart. Journ. Geol. Soc. vol. xliii. p. 63.

Fossils from Brendola have the central avicularium somewhat lower than in Hincks's figure. The two "pores" at the side are the ends of tubes; and in a few instances these only are visible, and the central avicularium is sometimes wanting. The ovicell is small and somewhat immersed. The preservation of this species is not good; but I feel little doubt that, even if not quite identical with the var. *porifera*, it is closely allied.

*Loc.* Living: Victoria; Bass's Straits; Queen Charlotte Island. Fossil: Waipukerau; Napier (New Zealand); Brendola; Ferrara di Monte Baldo.

44. Rhamphostomella brendolensis, sp. nov. (Pl. III. figs. 10, 11.)

Zoarium incrusting. Zoœcia distinct, oval to hexagonal; surface smooth, with large pores round the edge; peristome raised, with a peristomial notch either central or slightly to one side; on one side of the peristome a small triangular avicularium and in some parts of the zoarium also large elliptical avicularia on one side of the zoœcium, directed laterally. Sometimes the zoœcia are separated by a wall which is considerably raised vertically, and in some cases the subradiate lines on the surface are very distinct. Within the peristome there is an expanding lyrula; but the cardellæ are indistinct. Ovicells wide, raised or partly immersed, widely open in front, apparently not perforated.

*Rhamphostomella* is a genus established by Lorenz*, and of which Mr. Hincks † has given a revised diagnosis; from this the present fossil differs in having pores round the border of the zoœcia, and in apparently not having the ovicell perforate. It is, however, so clearly allied to forms placed under *Rhamphostomella* that the diagnosis of the genus must be altered to include it. It is not, however, yet quite certain that the genus is based upon satisfactory characters.

*Loc.* Fossil: Brendola; Montecchio Maggiore (?); Val di Lonte.

45. Porina (?) coronata (Reuss). (Pl. IV. figs. 1–5, 15.)

*Cellaria coronata*, Reuss, Foss. Polyp. Wien. Tert. p. 62, pl. viii. fig. 3.

*Eschara conferta*, Reuss, *op. cit.* p. 71, pl. viii. fig. 32.

*Acropora coronata*, Reuss, Bryoz. von Crosaro, p. 277, pl. xxxiv. figs. 3–5.

*Porina coronata*, Koschinsky, Bryoz. ält. Tert. südl. Bayerns, p. 42, pl. iv. figs. 7–9.

This is a most variable species, and the study of better-cleaned specimens and the preparation of further sections have led me to alter my views very materially. I have found it extremely difficult to satisfy myself as to the suboral pore, since the tube from the suboral avicularium and the suboral pore end close together, near to the oral aperture; but I have at last obtained sections showing that, contrary to what I thought from earlier preparations, the suboral pore enters the zoœcial cavity just below the oral aperture. This is very important, as it shows that, if we are to consider the position of the suboral pore as of first moment, this species must be removed from *Porina*; and as the position of the pore is nearly the same in *Tubucellaria cereoides*, we may have to remove it to *Tubucellaria*.

There is considerable variation in the shape of the zoarium, it being sometimes cylindrical, at others compressed; and there is also great variation in the pores or avicularia round the aperture, which are sometimes scarcely distinguishable from those covering the front of the zoœcia; in other cases they are very distinct; and there is usually a triangular avicularium directed distally just below the oral aperture and above the suboral pore. In some zoaria there are a few large raised avicularia with broadly spatulate openings, and these seem to be merely suboral avicularia modified.

Sections of the interior show the tubular connections from zoœcia to zoœcia, to which I referred in my 'Challenger' Supplementary Report, p. 32. The branches dichotomize; and in a few cases there are at the distal end of the branch openings for the chitinous tubes, showing that there has been articulation. In the specimen fig. 4 a fracture has taken place where the stem becomes thinner, presumably after death. In the slender forms, such as fig. 5, there

* "Bryozoen von Jan Mayen, Internationale Polarforschung," Akad. Wissensch. vol. iii. p. 93.

† Ann. Mag. Nat. Hist. ser. 6, vol. iii. p. 424.

is sometimes a calcareous basal attachment; but in the stouter forms I have seen nothing to indicate how it is attached. In some specimens a calcareous disk forms a closure over the aperture; and from this calcareous growth a tubule rises up in the middle (figs. 2 & 15).

A closure with a tubule occurs in several *Cyclostomata*, as in *Diastopora*, &c.; but I had always looked upon a closure of this kind as confined to the *Cyclostomata*, whereas we now find it in *P. coronata* and *Lepralia syringopora*.

There are a number of slender specimens (fig. 5) in which the proximal part of the peristome is often raised; and this appears to me like the *Cellaria labrosa* of Reuss (Foss. Polyp. Wien. Tert. pl. vii. fig. 38); but Reuss seems subsequently to have considered that this figure represented *Porina duplicata*.

*Loc.* Val di Lonte; Montecchio Maggiore (*Rss. & Waters*); Brendola; Crosaro; Ferrara di Monte Baldo; Ronzo; Malo; Priabona; Götzreuth (*Kosch.*); Wola Lu'zanska (*Perg.*); Eocene of Hungary (*Perg.*).

46. Porina (?) duplicata (Reuss). (Pl. III. fig. 14.)

*Cellaria duplicata*, Reuss, Foss. Polyp. Wien. Tert. p. 62, pl. vii. fig. 34.

*Eschara duplicata*, Reuss, Bryoz. von Crosaro, p. 273, pl. xxxiii. figs. 8–10.

*Eschara heterostoma*, Reuss, *op. cit.* p. 274, pl. xxvi. fig. 5.

Most of the specimens in my collection have the zoarium in the *E. duplicata* shape; but, according to our present ideas, there is no reason for separating this from *E. heterostoma*.

At the side of the peristomatal aperture there is a large triangular avicularium, forming a part of the peristome. The ovicell is recumbent, not much raised, or subimmersed. We are not yet acquainted with the oral aperture of this species; but Kirkpatrick has shown that *Gigantopora lyncoides* has a Schizoporellidan aperture. The large peristomial pore occurs in *Gigantopora lyncoides*, Ridley *, *Hippothoa fenestrata*, Smitt †, and *Porina* (?) *columnata*, Waters ‡, and cannot be looked upon as a good generic character.

*Loc.* Val di Lonte and Montecchio Maggiore (*Rss. & Waters*); Brendola; Ferrara di Monte Baldo (*W.*); Ronzo (*W.*); Malo; Pap-Patak, Hungary (*Pergens*), as *E. heterostoma*; Kolos-Monostor (*Pergens*).

47. Porina (?) papillosa (Reuss). (Pl. III. fig. 19.)

*Eschara papillosa*, Reuss, Polyp. Wien. Tert. p. 68, pl. viii. fig. 22; id. Foss. Foram. &c. von Oberburg, p. 31, pl. x. figs. 7–8; id. Bryoz. von Crosaro, p. 268, pl. xxxi. figs. 11–17.

* Proc. Zool. Soc. 1881, p. 47, pl. vi. fig. 3; Ann. Mag. Nat. Hist. ser. 6, vol. i. p. 77, pl. vii. fig. 5.

† Floridan Bryozoa, p. 47, pl. vi. fig. 142.

‡ Quart. Journ. Geol. Soc. vol. xxxvii. p. 334, pl. xviii. fig. 88.

*Porina papillosa*, Koschinsky, Bryoz. ält. Tert. südl. Bayerns, p. 37.

The zoarium is narrow at the base, and here there are numerous openings, showing that there was an attachment by means of chitinous tubes*. The zoœcia, as seen at the side, are alternate.

In the best cleaned specimens I have but very rarely been able to find any suboral pore, though certainly occasionally there is a pore larger than the others, and in imperfectly cleaned specimens the lower part of the avicularium might be mistaken for a pore. Neither have sections revealed any such pore. We may, however, remember that in *Tubucellaria cereoides* the pore can be distinctly seen on the surface in some zoœcia, but not in all, though sections show that in all cases there is below the aperture a pore wider than the others and readily distinguished in structure.

At the side of the zoœcia, resting on the peristomial projection, there is a long acute avicularium.

The peristome is often very much raised, forming a long tubular projection, which may entirely curve over (fig. 19, *a*), and then the opening is wide and slit-like. Neither Reuss nor Koschinsky has fully appreciated this, and they have merely described these cells as closed, which is sometimes the case. A similar prolongation occurs in various *Tubucellariæ*, and has been described and figured by both Busk and myself (see Ann. Mag. Nat. Hist. ser. 5, vol. xx. p. 190, pl. v. fig. 10). Very often one row has all the zoœcia prolonged, the next plain, and the following one again raised, and so on; so that the raised rows are easily seen with the naked eye.

Sections show that just above the oral aperture the peristome expands internally on the proximal side, as if there had been a small chamber, thus reminding us, on a smaller scale, of the ovicell of *Turritigera stellata*, B.

Pergens gives this as a synonym with *Eschara cervicornis* (Plioc. Bryoz. von Rhodes, p. 25); but they are very different things.

In the recent *Tubucellaria cereoides* there is only one of the glands to which I referred in my 'Challenger' Suppl. Report, pp. 2 & 27; and to these glands I hope shortly to refer elsewhere, having cut sections of a number of species with the object of finding how they occur.

Both this and *P. coronata* present us with so many difficulties with regard to characters, showing relationship with *Tubucellaria*, that the recent *Tubucellaria* must be re-examined with this object.

*Loc.* Brendola; Montecchio Maggiore; Val di Lonte; Ronzo; Crosaro; Malo; Götzreuth; Oberburg; Neustift (*Kosch.*).

48. Porina (?) biocul**a**ta, sp. nov. (Pl. III. fig. 15.)

A small specimen from Brendola is incrusting. Zoœcia not much raised, with peristome prolonged into a kind of neck, on the front of which are two large pores. On one side, about halfway down

* Koschinsky says, p. 37, that "Sie sind mit verbreiterter Basis festgewachsen;" but this I have never found to be the case.

the zoœcium, there is an avicularium directed inwards; and there is a row of pores around the border of the zoœcium. Ovicell recumbent.

This is clearly related to *Porina larvalis*, MacGillivray, which also has two large pores on the front of the peristome, and has an avicularium about halfway down the zoœcium. This last occurs fossil in Mount Gambier and Bairnsdale (Australia).

49. Schizoporella Hoernesi (Reuss). (Pl. IV. fig. 8.)

*Eschara Hoernesi*, Reuss, Bryoz. von Crosaro, p. 273, pl. xxxiii. figs. 6, 7.

*Schizoporella Hoernesi*, Koschinsky, Bryoz. ält. Tert. südl. Bayerns, p. 47.

*Cellaria scrobiculata*, Reuss, Foss. Polyp. Wien. Tert. p. 63, pl. viii. fig. 4.

Now that we know the shape of the oral aperture, it would seem that *S. Hoernesi* is the same as the *Schizoporella submersa* which I described from Curdies Creek (Quart. Journ. Geol. Soc. vol. xxxvii. p. 340, pl. xviii. fig. 85).

*Loc.* Val di Lonte; Montecchio Maggiore; Brendola; Götzreuth (*Kosch.*); Curdies Creek, S.W. Victoria; Kolos-Monostor (*Perg.*).

50. Schizoporella squamoidea (Reuss).

*Lepralia squamoidea*, Reuss, Fauna des deutschen Oberoligocäns, p. 19, pl. xv. fig. 5; Fauna des Septarienthones, p. 172, pl. vii. fig. 3; Bryoz. von Crosaro, p. 254.

The small zoœcia (0·3 mm. long) have small pores over the surface, and this sometimes shows indications of slight furrowing; the small aperture has a wide sinus; ovicells wide, globose.

The *Lepralia rugulosa*, Rss., differs from this in not having pores on the surface, and *S. hyalina* shows the same difference and a larger ovicell, but no doubt they are closely allied.

*Loc.* Bünde and Söllingen (*Rss.*); Val di Lonte; Montecchio Maggiore; Brendola; Crosaro (*Rss.*).

51. Schizoporella unicornis (Johnst.).

*Cellepora tetragona*, Reuss, Polyp. Wien. Tert. p. 78, pl. ix. fig. 19.

*Schizoporella unicornis*, Hincks, Brit. Mar. Polyz. p. 238 (which see for synonyms).

*Loc.* Living: widely distributed. Fossil: Montecchio Maggiore; Austrian and Hungarian Miocene; Crag; Pliocene of Italy.

52. Schizoporella serrulata (Reuss).

*Cellepora serrulata*, Reuss, Polyp. Wien. Tert. p. 85, pl. x. fig. 12.

A specimen from Montecchio Maggiore more nearly corresponds with Reuss's original figure than with those in Bryoz. Oest.-Ung. Mioc. p. 167, pl. ii. figs. 2, 3, pl. iv. fig. 4. In a young zoœcium the

oral aperture is seen to have a wide round sinus. In older zoœcia there is a plate inside the proximal part of the aperture sloping inwards, as shown in Reuss's recent figure, pl. iv. fig. 4, called *S. crassilabris* on the plate. The ovicell is small and hood-shaped, as shown in the first figure, and also in fig. 4, pl. iv. Just above the peristome, or ovicell, there is an opening on one or both sides, which may have been vibracular.

*Loc.* Eisenstadt (*Rss.*); Montecchio Maggiore.

53. Schizoporella Omboni (Gottardi).

*Lepralia Omboni*, Gottardi, Brioz. foss. di Montecchio Maggiore, Atti Soc. Veneto-Trentina di Sc. Nat. vol. ix. p. 305, pl. xiv. fig. 1.

Zoarium incrusting; zoœcia distinct, separated by a raised line; on the surface there are a few large pores mostly near the border, and there is a triangular avicularium about halfway down the zoœcium, sometimes one on each side. The ovicell is not prominent, and looks like a cap to the aperture. The sinus is wide.

This is closely allied to *S. Hoernesi*, Rss., and it is doubtful whether it should be separated on account of the mode of growth and the distribution of the pores over the surface. It differs from *Eschara fissimargo*, Rss., in having a row of pores. Probably *Lepralia monopora*, Rss. (Bryoz. von Crosaro, p. 45), is described from a worn specimen of the present species.

*Loc.* Montecchio Maggiore (*Gottardi*); Brendola; Val di Lonte; Malo.

54. Schizoporella phymatopora (Reuss).

*Eschara phymatopora*, Reuss, Bryoz. von Crosaro, p. 272, pl. xxxiii. fig. 1.

From Australia I have described similar cylindrical forms as *S. phymatopora*. They differ in usually having the avicularium placed much lower, but the position is not constant (see Quart. Journ. Geol. Soc. vol. xxxvii. p. 338, pl. xv. figs. 31, 32; vol. xxxviii. p. 510; vol. xli. p. 300).

*Loc.* Val di Lonte (*Rss.*); Brendola; Lower Eocene of Mons (*Munier & Pergens*).

55. Schizoporella Schreibersi (Reuss).

*Cellaria Schreibersi*, Rss. Foss. Polyp. Wien. Tert. p. 63, pl. viii. fig. 8; Bryoz. von Crosaro, p. 262, pl. xxiv. figs. 5, 6.

The aperture has a wide round sinus; the presence of avicularia is not quite constant, but there is usually one on each side, sometimes raised, but usually flat with the surface. Closely allied to *S. australis*, Woods (see Quart. Journ. Geol. Soc. vol. xxvii. p. 341, pl. xiv. fig. 15). The zoarium is only about 0·4 millim. wide.

*Loc.* Val di Lonte and Montecchio Maggiore (*Rss.*); Brendola; Pap-Falva and Kolos-Monostor, Hungary (*Perg.*).

56. Schizoporella ternata (Reuss). (Pl. IV. figs. 11, 12.)

*Lepralia ternata*, Rss. Bryoz. Oest.-Ung. Mioc. p. 167, pl. iii. fig. 11, pl. vii. fig. 5.

There is a projection at the side of the aperture, frequently supporting an avicularium; and in one specimen there is also an avicularium below the aperture, rather to one side. The ovicell is small and globular. None of the specimens are well preserved; and probably many names have been given to this species.

*Loc.* Nussdorf; Eisenstadt; Brendola; Val di Lonte; Montecchio Maggiore.

57. Fedora excelsa (Koschinsky). (Pl. IV. fig. 6.)

*Kionidella excelsa*, Koschinsky, "Bryozoenfauna der ält. Tert. südl. Bayerns;" Palæontographica, vol. xxxii. p. 68, pl. vii. figs. 5–12.

I have one specimen from the Bocca di Sciesa, Colle Berici, and another from Brentonico*, Mt. Baldo, which differ in a few particulars from Koschinsky's description; but the differences do not seem sufficient to separate them specifically. As far as can be seen, the zoarium is throughout a solid cylinder and not tubular; there is a kind of hood above the aperture, and usually a large lanceolate avicularium at each side. The ovicell is large, wide, raised, and perforated, apparently somewhat like the ovicell of *Schizoporella tuberosa*; but the state of preservation is not sufficient to permit of a full description.

This is no doubt the *Fedora* of Jullien †; but Dr. Jullien described and figured it upside down, as the growth is from the tip of the zoarium (the right-hand side of his fig. 39). I give a figure (fig. 7) of the operculum of *Fedora Edwardsi*, Jullien, showing that the zoœcial characters are Lepralian.

Specimens from Spiassi (halfway between Caprino and Ferrara di Monte Baldo) have a small conical zoarium (3–4 millim. long); and from the shape I thought it was *Batopora conica*, Hantk.

*Loc.* Götzreuth, Bavaria (*Kosch.*); Brentonico; Bocca di Sciesa; Colle Berici; Spiassi; Malo.

58. Retepora tuberculata, Reuss.

*Retepora tuberculata*, Reuss, Bryoz. von Crosaro, p. 267, pl. xxxi. figs. 9, 10.

There is a pit below the aperture, which may be avicularian; but in the Brendola specimens these pits do not occur with the regularity figured by Reuss, and there are also other small avicularia scattered about in various positions, and occasionally an enlarged avicularium.

*Loc.* Val di Lonte (*Rss.*); Brendola.

* Brentonico is on the north part of the Monte Baldo range, a few miles south of Mori.

† "Dragages du Travailleur," Bull. Soc. Zool. de France, vol. vii. p. 17.

59. Retepora elegans, Reuss. (Pl. IV. figs. 9, 10.)

*Retepora elegans*, Rss. Foss. Polyp. Wien. Tert. p. 48, pl. vi. fig. 38.

There are only unbranched fragments from Brendola. The suboral pore is at the end of a groove. The ovicells are recumbent; and there is sometimes a ligulate avicularium on the front of the zoœcium. The zoœcia are wide at the distal end, but narrow at the proximal; the lateral zoœcia are obliquely arranged; and this gives the dorsal surface a very characteristic appearance, with the zoœcia turned alternately to the right and the left.

*Loc.* Reuss's description is from a specimen from the Val di Lonte; Brendola.

60. Cellepora proteiformis, Reuss. (Pl. IV. figs. 13, 14.)

*Eschara diplostoma*, Reuss (*non* Phil.), Foss. Polyp. Wien. Tert. p. 71, pl. viii. fig. 34.

*Celleporaria proteiformis*, Reuss, Bryoz. von Crosaro, p. 264, pl. xxx. figs. 2, 6–8.

*Cellepora diplostoma*, Pergens, Bryoz. von Wola Lu'zanska, p. 72.

This is one of the holostomatous* *Celleporæ*, with a large triangular avicularium at one side below the aperture, and with a large globular ovicell, perforated in the same way as the surface of the zoarium. At present only two *Celleporæ* are known living from the northern hemisphere having the lower edge of the oral aperture straight, namely *C. sardonica*, Waters, and *C. pertusa*, Smitt; but the group is better represented in the southern hemisphere; and it is interesting to find this species very abundant in the Lower Tertiaries. In one specimen I have found a large spatulate vicarious avicularium.

In the specimen, fig. 14, on one side all but three zoœcia are flat, with large pores on the surface; but the three are raised in a somewhat ovoid shape, and are at once seen to resemble the zoœcia of *C. proteiformis*. Turning the fragment over, we find that on the other side about one-half of the zoœcia are raised above the surface, like big ovicells; and there is now no difficulty in recognizing this as a stage of *C. proteiformis*. It was only, however, at the eleventh hour that the flat, compressed form, and the cylindrical one, consisting of several layers, were seen to be stages of the same species.

The description and figure of *E. diplostoma* are so insufficient that

* MacGillivray proposes to leave these to form the genus *Cellepora*, while he calls those with a schizostomatous aperture *Schismopora*. As the latter were the earliest known, it might have been better to give a new name to the holostomatous group, but this is not a matter of much importance. In 1881 I pointed out that there were a number of *Celleporæ* with the oral aperture straight below, and that, perhaps, they should form a subgenus. For a long time workers have recognized that *Cellepora*, as understood, could not stand; and, therefore, when Jullien reproaches us for retaining the genus, it shows an imperfect acquaintance with our work; and I still maintain that science has been better served by showing relationship and collecting facts than by premature classification.

Reuss, in my opinion, was justified in giving it another name; moreover, "*diplostoma*" had already been used by Philippi.

Pergens is mistaken in supposing that it has been found in the Vienna Tertiaries, though, as mentioned, the Val di Lonte material was for a time supposed to come from the Vienna Basin.

*Loc.* Val di Lonte and Montecchio Maggiore (*Rss.*); Brendola; Ferrara di Monte Baldo; Ronzo; Wola Lu'zanska.

61. Cellepora oligostigma, Reuss.

*Lepralia oligostigma*, Reuss, Bryoz. von Crosaro, p. 257, pl. xxxvi. fig. 10.

There are two incrusting specimens from Montecchio Maggiore; and the ovate zoœcia are in one case arranged in a radiate manner. The peristome is raised, and an avicularium at the side forms part of it, just as in *Porina duplicata*; but there is no suboral pore, the avicularian chamber is larger, and the shape is more distinctly seen from the outside, thus causing greater irregularity of appearance. The ovicells are globular, recumbent, perforated. The oral aperture is, no doubt, nearly round; but it has not been possible to see the exact shape: probably *oligostigma* belongs to the *Schismopora* group.

*Loc.* Crosaro (*Rss.*); Montecchio Maggiore.

62. Cellepora pertusa, Smitt.

*Orbitulipora lenticularis*, Reuss, Bryoz. von Crosaro, p. 289, pl. xxx. figs. 12–14; Pergens, Foss. Bryoz. von Wola Lu'zanska, p. 72.

In a specimen from Val di Lonte, not well preserved, the ovicells are broken down, but the oral apertures are nearly straight below and about 0·15 millim. wide. I have mentioned a subglobular *C. pertusa* from Aldinga (Quart. Journ. Geol. Soc. vol. xli. p. 305). Marsson (Bryoz. Schreibkreide der Insel Rügen, p. 101) says that *O. lenticularis*, Reuss, is the *Cellepora accumulata* of Hagenow; though, from the description and figures, it is impossible to be sure of this.

A cylindrical specimen from Montecchio Maggiore also has the *pertusa* aperture and a suboral avicularium; but neither is the preservation of this satisfactory.

63. Stichoporina simplex, Koschinsky. (Pl. IV. figs. 16–18.)

*Stichoporina simplex*, Kosch. Bryoz. ält. Tert. südl. Bayerns, p. 64, pl. vi. figs. 4–7.

From Brendola this occurs in a disk form; in *Cupularia*-form; and in flat pieces which must have been from a larger growth.

The zoœcia are raised and rounded, with the oral aperture slightly coarctate, nearly central, somewhat depressed; on the right side of many zoœcia there is a large triangular avicularium with a bar across. Out of a number of specimens, I have only found one zoœcium with an avicularium on the left side. Some pieces have an avicularium to almost every cell, others only to one or two zoœcia.

In one small specimen (fig. 18) there is above many zoœcia a thick curved bar, somewhat thicker at the base; but, as the cells are a good deal crushed, I am not sure to what extent the appearance may be due to this. As there is matrix between the zoœcia, the drawing is in certain parts a restoration. This small specimen shows a relationship to *Stichoporina crassilabris*, Koschinsky; but in other specimens the relationship is not so apparent.

The dorsal surface shows the base of each zoœcium as a much raised rounded area, with a few large pores.

There are two specimens (fig. 17) with rather smaller zoœcia, but with a similarly shaped aperture, but slightly smaller; and, as a rule, there are no avicularia, though zoœcia with ovicells have a small avicularium on one or both sides. The ovicell is not very much raised, partly immersed, and is merely an enlargement of the distal end of the zoœcium. This might perhaps be called var. *minor*.

Zoœcia seen laterally, as on the free border of the zoœcium, show a contraction about a quarter of the height from the base; and there are here two rosette plates or pores to each zoœcium.

This is allied to *S. protecta* and *S. crassilabris* from Götzreuth; and the zoœcia resemble those of *Kionidella obliquiseriata*, Kosch., *op. cit.* pl. vii. fig. 13 *b*; and it would seem that the two genera should be united. At first, when I had only examined specimens which were not thoroughly cleaned, I took this for *Cupularia bidentata*, Reuss, as the avicularia are very prominent. I have not found *C. bidentata* in either locality, and feel in doubt about it *.

*Loc.* Götzreuth (*Kosch.*); Brendola; Ronzo; Pap-Falvi-Patak.

64. Batopora multiradiata, Reuss.

*Batopora multiradiata*, Reuss, Bryoz. von Crosaro, p. 265, pl. xxxi. figs. 1–4.

The zoœcia are barrel-shaped, with a semicircular aperture, straight below (about 0·1 millim. wide), and a recumbent ovicell, which, however, is directed towards the apex of the zoarium.

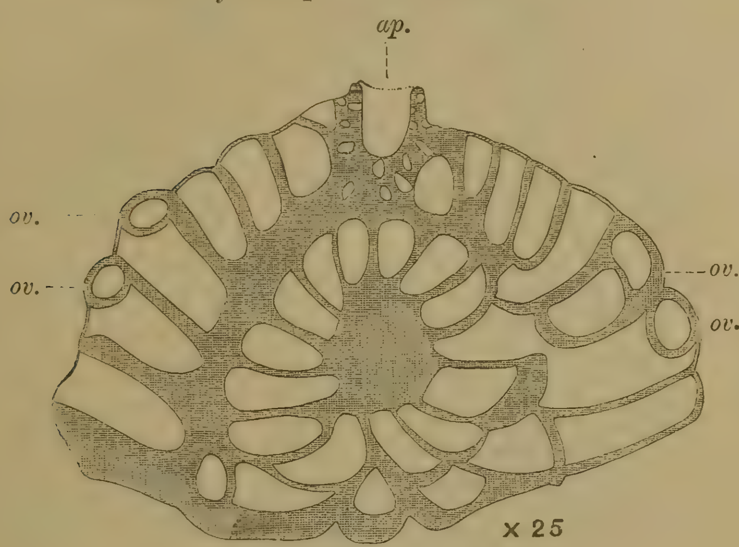
In the shape of the zoœcia, the aperture, and the ovicell, this is very similar to the *Orbitulipora* of the Chalk and Lower Oligocene; and the two genera are clearly closely allied even if separation is necessary.

In *Orbitulipora petiolus* (Lonsd.) the ovicell is also directed towards the centre of the zoarium. It is difficult to understand how *Batopora* grew, for it does not seem to start from the large round cell at the apex, as there is a layer of zoœcia below that. It appears

* [A specimen sent me by Dr. Pergens from Pap-Falvi-Patak as *Cupularia bidentata*, Rss., is *S. simplex*, K. Since this paper was read Mr. R. Kirkpatrick, of the Natural-History Museum, has submitted to me a specimen, from Murray Island (15–20 fath.), of recent *Stichoporina*, which I should call *S. simplex*. The aperture is rather wider and rounder than in the fossils, and it may have to be separated as a variety on this account, though the shape of the zoœcia, the position of the avicularium, and the structure of the dorsal surface are the same in both. Mr. Kirkpatrick informs me that he has also had it from the Cape of Good Hope and Malacca; and we may look for a description from his pen very shortly.—A. W. W., December 24th, 1890.]

more probable that it grows from a central basal cell, gradually forming a nearly globular zoarium; and then from the apex of this a second layer is formed, and perhaps a third. Some specimens are thus partially capped with a growing layer. (See woodcut.)

*Section of* Batopora multiradiata, *Reuss.*




*ap.*, apical cell; *ov.*, *ov.*, ovicells.

*Loc.* Val di Lonte and Priabona (*Rss.*); Brendola (*Waters*); Ferrara di Monte Baldo (*W.*); Montecchio Maggiore (*Gottardi & W.*); Ronzo (*W.*); Malo. Eocene of Bavaria (*Pergens*). Various Hungarian localities (*Pergens*).

65. Batopora? Stoliczkai, Reuss.

*Batopora Stoliczkai*, Reuss, Bryoz. deutsch. Unteroligoc. p. 223, pl. ii. figs. 2–4.

The globular zoaria from Brendola vary from 1 millim. to 3 millim. in diameter, and at first I thought the small ones might be young zoaria of *Batopora multiradiata*; but the size of the larger specimens shows that this cannot be the case. The aperture is not round, but flattened on the lower side, so that it does not differ much from that of *B. multiradiata*, Reuss.

*Loc.* Unteroligocän of Calbe (*Rss.*); Montecchio Maggiore (*Gottardi*); Brendola.

66. Lunulites quadrata, Reuss.

*Cellepora quadrata*, Reuss, Foss. Polyp. Wien. Tert. p. 95, pl. xi. fig. 17.

*Lunulites quadrata*, Reuss ("*tetragona*" on the plate), Bryoz. von Crosaro, p. 278, pl. xxviii. fig. 18.

In a large specimen from between Grotte and Sarego, Colle Berici, the proximal edge of the aperture is straight, and the avicularia are larger than figured. There are no doubt many synonyms for this (see Quart. Journ. Geol. Soc. vol. xxix. p. 442).

## EXPLANATION OF PLATES I.–IV.*

The figures are magnified 25 times, except those otherwise marked.

### Plate I.

Figs. 1–6. *Catenicella septentrionalis*, sp. nov. *a*, aperture, magn. 85 times. (Fig. 5, dorsal surface.)
7, 8. —— ——, var. (Fig. 7, dorsal.)
9, 10. —— *continua*, sp. nov. (Fig. 10, dorsal.)
Fig. 11. *Catenaria tenerrima*, Reuss. (*a*, aperture, magn. about 50 times.)
Figs. 12, 13. *Scrupocellaria gracilis*, Reuss. (Fig. 13, dorsal.)
14, 15. —— *brendolensis*, sp. nov. (Fig. 15, dorsal.)
16, 17. —— *elliptica*, Reuss. (Fig. 17, dorsal.)
18, 19. *Bactridium Hagenowi*, Reuss. (Fig. 18, dorsal.)
Fig. 20. *Onychocella angulosa*, Reuss; form *excavata*, Reuss.
Figs. 21, 22. *Scrupocellaria montecchiensis*, sp. nov. (Fig. 22, dorsal.)
Fig. 23. *Vibracella trapezoidea*, Reuss.

### Plate II.

Figs. 1, 2. *Membranipora Rosselii*, Aud., var. *deplanata*, Reuss.
Fig. 3. —— *appendiculata*, Reuss.
4. —— *Dumerillii*, Aud.
Figs. 5, 6. *Micropora articulata*, sp. nov.
Fig. 7. —— *polysticha*, Reuss.
8. —— *parallela*, Reuss.
9. —— *coriacea*, Esper.
10. *Cribrilina chelys*, Koschinsky. The ovicell and vicarious avicularium are added from different parts of the colony.
11. *Monoporella sparsipora*, Reuss. From Montecchio Maggiore.
12. *Lepralia subchartacea*, d'Arch.
Figs. 13, 14. —— *nodulifera*, Reuss. From Brendola.
Fig. 15. —— *impressa*, Reuss.
Figs. 16–18. —— *bisulca*, Reuss. From Brendola.

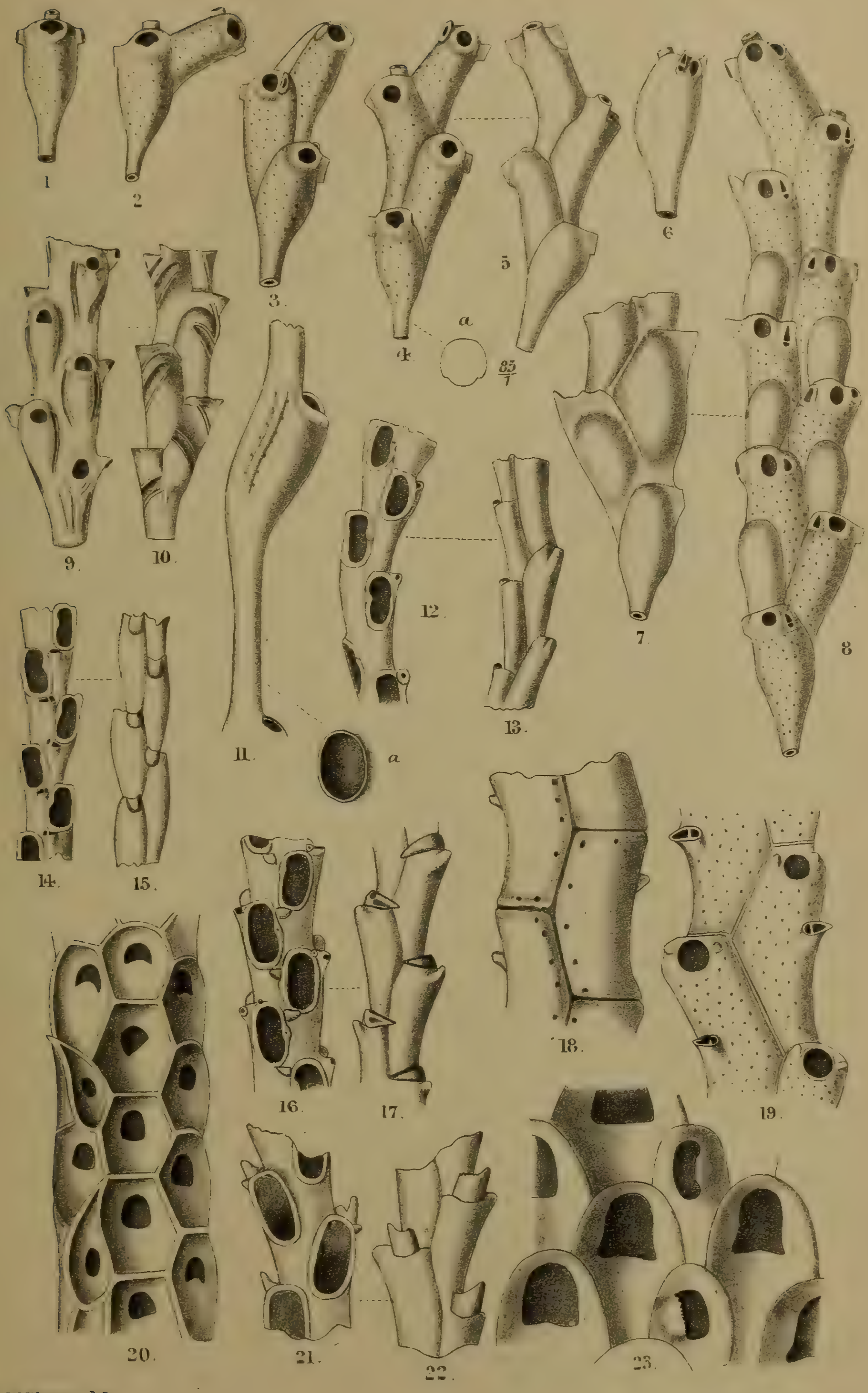
### Plate III.

Fig. 1. *Lepralia bisulca*, Reuss. From Brendola.
Figs. 2–4. —— *syringopora*, Reuss.
Fig. 5. —— *lontinensis*, sp. nov.
6. *Smittia exarata*, Reuss.
7. —— *coccinea*, Abild., var. *alifera*, Reuss. From Brendola.
8. —— *coccinea*, Abild.
9. —— *porrigens*, Reuss.
Figs. 10, 11. *Rhamphostomella brendolensis*, sp. nov. (Fig. 10 *a*, magn. 50 times.)
Fig. 12. *Smittia chilopora*, Reuss.
13. *Porella marsupium*, var. *porifera*, Hincks.
14. *Porina* (?) *duplicata*, Reuss.
15. —— *bioculata*, sp. nov.
Figs. 16, 17. *Porella imbricata*, Reuss.
Fig. 18. *Lepralia* (?) *bericensis*, sp. nov.
19. *Porina papillosa*, Reuss. *a*, tubular curved peristome.

### Plate IV.

Figs. 1–3. *Porina coronata*, Reuss.
Fig. 4. —— ——. Termination, showing openings for articular tubes.
5. —— ——. Small form, like *labrosa*, Reuss.
6. *Fedora excelsa*, Koschinsky. (Fig. 6 *a*, magn. twice.)
7. —— *Edwardsi*, Jullien. Operculum.
8. *Schizoporella Hoernesi*, Reuss.
Figs. 9, 10. *Retepora elegans*, Reuss. (Fig. 9, dorsal.)
11, 12. *Schizoporella ternata*, Reuss.
13, 14. *Cellepora proteiformis*, Reuss.
Fig. 15. Diagrammatic section of *Porina coronata*, Reuss.
Figs. 16–18. *Stichoporina simplex*, Koschinsky.

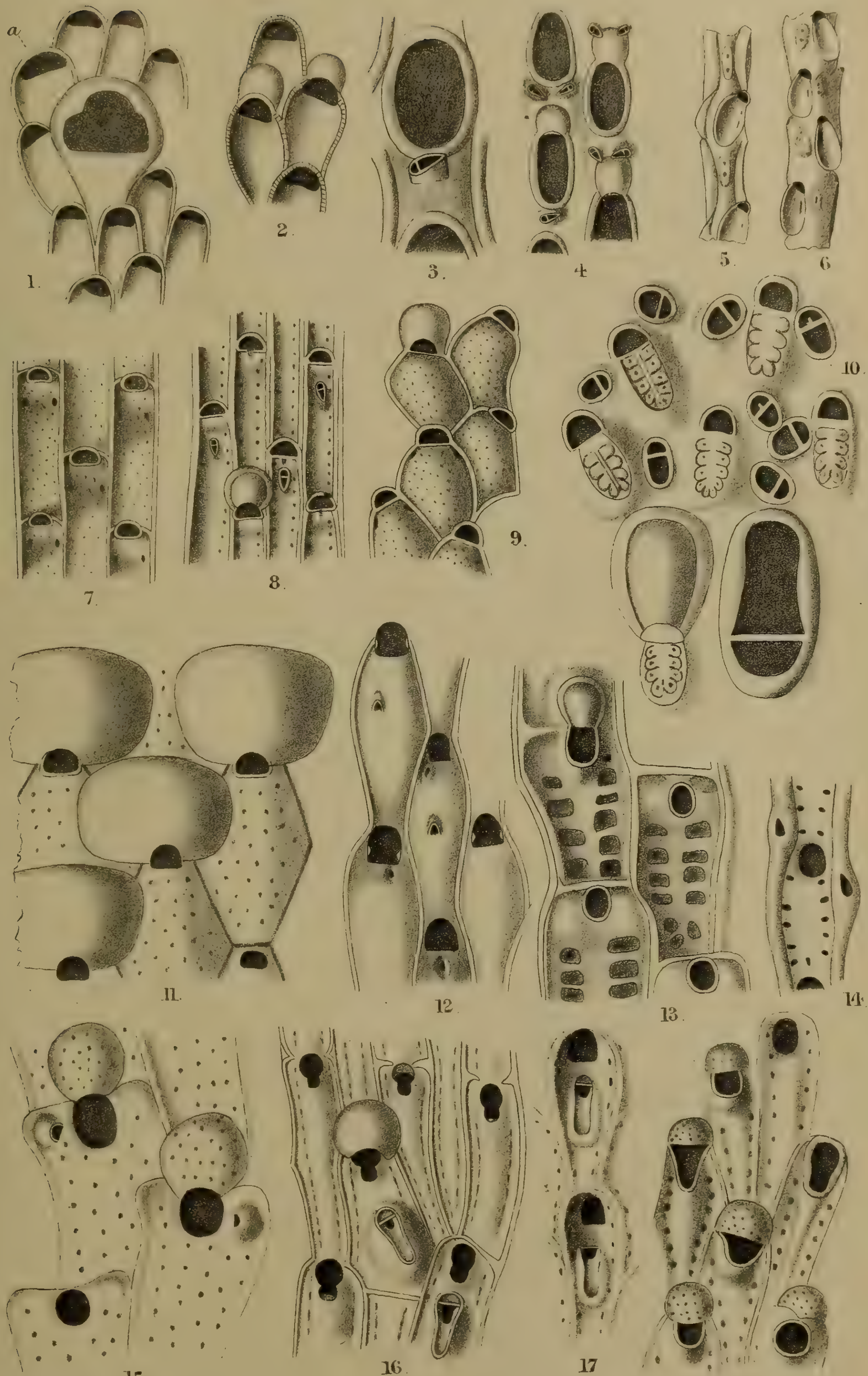
* These have been drawn at the Author's expense.




A. W. Waters del.
M. P. Parker lith.

Mintern Bros. imp.

NORTH-ITALIAN BRYOZOA.




A. W. Waters del.
M. P. Parker lith.

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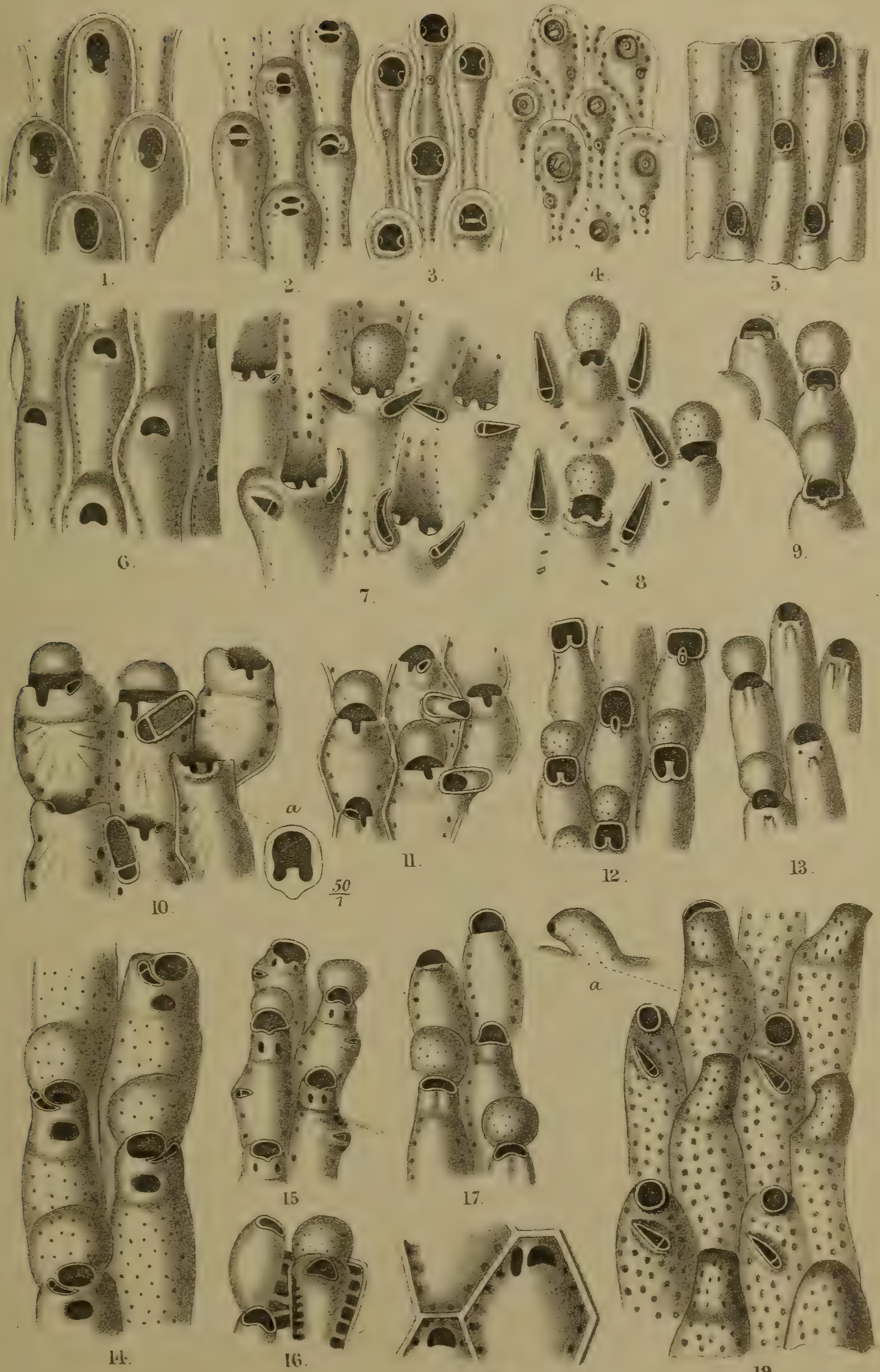
NORTH-ITALIAN BRYOZOA.

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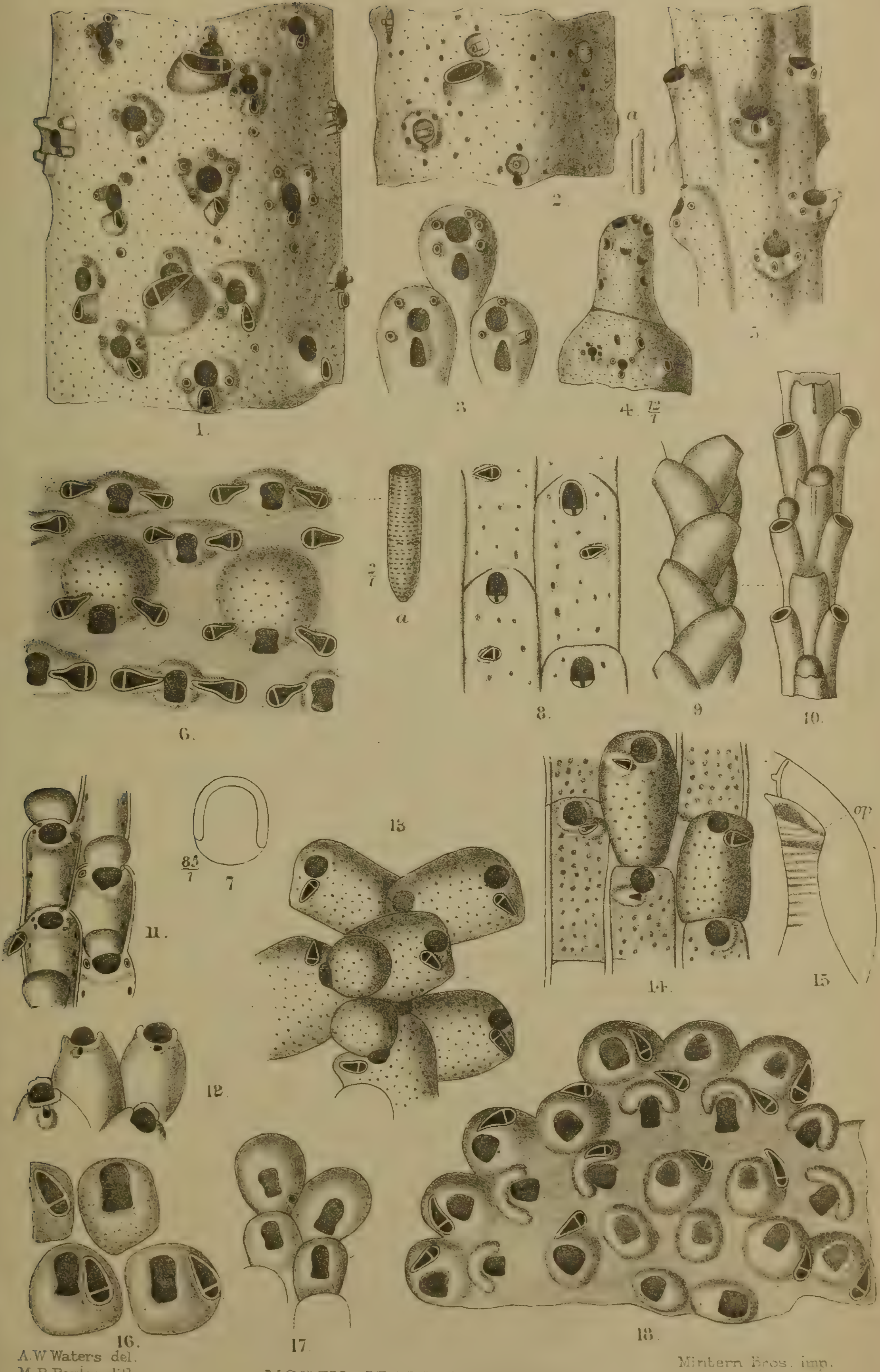



A.W. Waters del.
M.P. Parker lith.

NORTH-ITALIAN BRYOZOA.

Mintern Bros. imp.

2. *On the* Porphyritic Rocks *of the* Island *of* Jersey. By Prof. A. de Lapparent, Foreign Correspondent of the Society. (Read November 12, 1890.)

(Communicated by the President.)

Having been supplied some years ago, through the kindness of my friend the Rev. C. Noury, of St. Helier, with a good series of specimens of porphyritic rocks from the Island of Jersey, I was struck by the exceptional appearance of some felsitic and globular varieties, in which the spheroidal concretions, instead of being minute globules, as in the usual pyromerides, attained a size of two feet and more in diameter. According to the information which I then possessed, the porphyritic rocks occupied the whole of the north-eastern part of the Island, resting on Cambrian schists, and underlying, from Rozel to St. Catherine's Bay, a coarse conglomerate, which had been described by Ansted as *New Red Sandstone.*

At that time I strongly advocated the views entertained by my distinguished friend M. Michel-Lévy, on the relation between structure and geological age in eruptive rocks; and, judging from many examples collected in various districts of France, I believed that every felstone and pyromeride would be found to be of Permian age. Accordingly, as this belief seemed to be warranted by the facts in Jersey, I described the whole of the porphyritic rocks of the Island as Permian *. Moreover, I even ventured to lecture my English predecessors for having failed to recognize the true age of the eruptive series, the felsites of Jersey having been described by Mr. Davies as "*old rhyolites.*" This was a mistake on my part, which I now feel myself bound to confess before the Geological Society of London.

The first doubts as to the correctness of my theoretical views arose in my mind immediately after the Meeting of the Geological Congress in London in 1888. I had taken part in the excursion to North Wales, under the guidance of Dr. Hicks, and had there observed the intercalation of true felsites in the "Precambrian slates," while numerous boulders of the same felsites were to be found among the constituents of the conglomerate which underlies the purple slates of Llanberis. Accordingly I could no longer hesitate to believe that eruptive rocks with true felsitic structure might belong to the earliest geological periods.

Some months later, my friends Mr. Hill and M. Bigot entered, each for himself, upon the geological study of the northern group of the Channel Islands. They both were led to the conclusion that the grits and conglomerates of these Islands, which are not to be separated from the conglomerate of the north-east corner of Jersey, and which also contain pieces of felsite and globular porphyry, ought

* Bulletin Soc. Géol. France, 3e sér. vol. xii. pp. 284–289.

to be considered as synchronous with the purple conglomerates of the Cotentin—that is, with the very base of the Silurian formations. On this view I could easily see that the porphyritic series of Jersey might represent something equivalent to the oldest felsites of North Wales. But having never visited the ground, and being desirous of correcting my error by actual inspection of the rocks *in situ*, I paid a visit to Jersey last summer.

At the first glance I could perceive that the porphyritic series, instead of being discordant with the schists, is intimately connected with that formation and partakes of its general strike and dip. At the base of the eruptive mass, tuffs and breccias prevail, which under the microscope prove to be mainly tuffs of porphyrites. Such are the rocks at Havre-Giffard, the so-called metamorphic schists, with large crystals of felspar, at the Imperial Hotel, and also the rocks which are worked at Stephen's Mill for road-material. Then comes, at Anne Port, a blood-coloured porphyritic mass, which looks quite like a red quartziferous felsite, but which, microscopically examined, proves to be a porphyrite with a large admixture of iron-bearing quartz, becoming in some places a true red jasper. This mass underlies the reddish felstones, with well-marked columnar structure, of La Crête and Archirondel, while the pyromerides of Boulay Bay form the top of the series, being, at the Tête des Hougnes (as clearly stated by the Rev. C. Noury, in his 'Géologie de Jersey'), immediately succeeded by the first purple-coloured layer of the Rozel conglomerate.

I do not intend to enter here into a more detailed study, which I am preparing for the Geological Society of France. But I thought it my duty to do justice to the geologists who had long ago recognized the true character of those "old rhyolites," which, from mistaken theoretical views, I had been led to regard as Permian eruptive rocks, although, in fact, when carefully examined, they exhibit very little in common with the true Permian porphyries of France or of Saxony.

## Discussion.

Mr. E. Hill considered the Author's former opinion was the natural consequence of Ansted's views. Messrs. Davies and Bigot's work had entirely overthrown these. He agreed with the Author as to the relation between the argillites and the porphyritic rocks, and awaited with interest the further information promised.

## 3. *On a* New Species *of* Trionyx *from the* Miocene *of* Malta *and a* Chelonian Scapula *from the* London Clay. By R. Lydekker, Esq., B.A., F.G.S. (Read November 12, 1890.)

### I. Trionyx from Malta.

In a paper read before the Society in November, 1885, I described part of a Crocodilian skull from the Miocene of the Maltese Islands, which was referred to the existing Oriental genus *Tomistoma* *; attention being at the time particularly directed to the interest of the occurrence, in those deposits, of a genus now confined to one island in the purely tropical Malay Subregion of the Oriental Region. On the present occasion I bring to the notice of the Society evidence of Oriental affinities in a member of the Chelonian family *Trionychidæ*, of which the remains have been recently obtained from the Miocene of Malta.

The specimen forming the subject of this part of the paper is one of a small collection brought from Malta by Dr. John Murray, and presented by him to the British (Natural History) Museum. It consists of a portion of the middle and right half of the anterior region of the carapace of a large Chelonian referable to the family *Trionychidæ*. The specimen, of which a reduced and restored representation is given in the accompanying figure, is embedded in the characteristic buff limestone of Malta, with the sculptured surface exposed. The nuchal bone (*nu*) is missing, but the greater part of the first four costals ($c^1$–$c^4$) of the right side are preserved; and there also remain portions of five neural bones, and the inner extremities of the first, second, and third costals of the left side. The form of the neural ($n^3$) situated between the third costals, with its shorter lateral surfaces placed posteriorly, is alone sufficient to show that the specimen belongs to the anterior half of the carapace. The forward inclination of the fourth costal is, however, apparently due to the flattening which the specimen has undergone.

The carapace indicates a species nearly or quite as large as the existing *Chitra indica*, the length of the third neural being 2·8 inches. It also agrees with that species in the coarseness of the sculpture, but this feature is also met with in some species of *Trionyx*. The comparative shortness of the ribs and costal plates suggests that the specimen is not fully adult.

Before proceeding further, it should be observed that the three Indian species of *Trionyx* (viz. *T. gangeticus*, *T. Leithi*, and *T. hurum*) differ from all other members of the family in having two neural bones between the first pair of costals †, this being apparently due to a subdivision of the normal first costal. All the fossil species hitherto described, of which the entire carapace is known, agree

* See Quart. Journ. Geol. Soc. vol. xlii. p. 20 (1886).

† See Boulenger, 'Catalogue of Chelonians, &c. in Brit. Mus.' p. 244 (1889).

with the normal type in having but a single long neural between the first pair of costals; and no species, so far as I am aware, has been named from the Maltese Miocene. An inspection of the figure of the Maltese specimen will, however, at once show that it agrees with the *T. gangeticus* group in having two neurals ($n^1$ and $n^{1a}$)

Fig. 1.—*Upper surface of the anterior part of the carapace of* Trionyx melitensis; *from the Miocene of Malta.* (One fourth of the natural size.)


between the first costals, and that it is therefore specifically distinct from all fossil species based on specimens sufficiently perfect to exhibit the characteristic features of this part of the carapace. From *T. gangeticus* and its allies it is distinguished by the greater elongation of the second moiety of the divided neural ($n^{1a}$), in consequence of which the proper second neural ($n^2$) becomes much shorter, and also by the coarser sculpture. In its coarse sculpture it agrees with *T. planus*, of the Hordwell beds, in which the anterior part of the carapace is unknown, but is of larger dimensions.

It has already been mentioned that in its large size and coarse sculpture the fossil approximates to *Chitra indica*; and the question naturally arises whether extinct species of *Chitra* may not, like the Indian species of *Trionyx*, have the first neural divided. In the absence of the skull it is almost or quite impossible to say whether

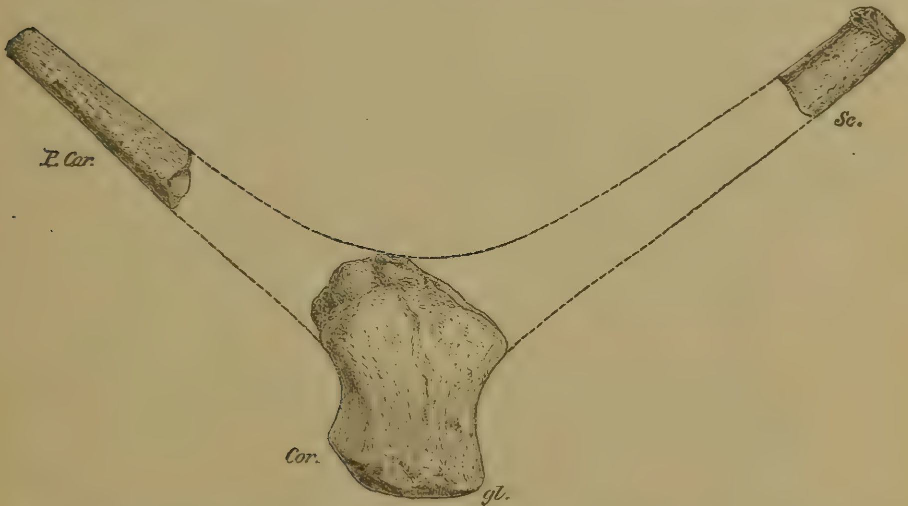
the fossil species should be referred to *Chitra* or *Trionyx*; but in either case its Indian affinities would be certain, since *Chitra*, like the species of *Trionyx* with a divided first neural, is now confined to India.

Since we know of the existence of a divided first neural in *Trionyx*, and have no evidence of such a condition in *Chitra*, I propose to refer the species represented by the specimen under consideration to the former genus, with the designation *T. melitensis*.

## II. Scapula of Eosphargis from the London Clay.

A short time ago Mr. W. H. Shrubsole, F.G.S., submitted to my notice three fragments of a large reptilian bone obtained from the London Clay of Sheppey, which I soon recognized as portions of the left scapula of a gigantic turtle. The fragments, which are represented in their approximately relative positions in fig. 2, indicate a larger scapula than has hitherto come under my notice; and the only known turtle, from these deposits, to which they can be referred is the so-called *Chelone gigas* of Owen, a species which I have made the type of the genus *Eosphargis*, and classed among *Dermochelyidæ**. The fragments comprise the glenoidal portion of the bone, the distal

Fig. 2.—*Ventral aspect of the left scapula of* Eosphargis gigas, *from the London Clay.* (One sixth of the natural size.)




*Sc.*, scapula; *P.Cor.*, precoracoid; *Cor.*, coracoidal facet; *gl.*, glenoid facet.

extremity of the true scapular bar, and a considerable portion of the precoracoidal bar. Among the specimens of *Eosphargis gigas* preserved in the British Museum is a slab of rock, numbered 44089†, which contains the imperfect bones of the pectoral girdle. In this specimen there is the glenoidal extremity of a scapula (or, as it may

* Quart. Journ. Geol. Soc. vol. xlv. p. 241 (1889).
† See 'Cat. Foss. Rept. & Amphib. Brit. Mus.' pt. iii. p. 226 (1888-89).

be more precisely termed, scapulo-precoracoid), partly concealed by the matrix. The exact transverse diameter of the "neck" of that scapula cannot be precisely determined, but it was evidently very considerably less than in the present specimen, where it is upwards of 6·7 inches.

The especial interest of the present specimen is that it is more like the scapula of *Chelone* than that of *Dermochelys*, this being especially shown by the sharpness of its ridges, notably the one at the junction of the inferior border of the precoracoid with the neck, and the long and triangular form of the facet for the articulation of the coracoid. Indeed, if we had no evidence of the existence of gigantic *Dermochelyidæ* in the London Clay, I should have been disposed to refer the specimen to a member of the *Chelonidæ*, by the side of which the *Chelone Hoffmanni* of Maastricht would be a dwarf.

Although too much stress should not be laid on the resemblance of this bone to the scapula of the *Chelonidæ*, yet it to a certain extent supports the very strong evidence lately brought over by Dr. Baur * as to the intimate affinity between the *Dermochelyidæ* and *Chelonidæ*; and I may take this opportunity of stating my belief that the writer here mentioned has practically proved his view that the so-called *Athecata* are nothing more than a specialized offshoot from the earlier *Chelonidæ*. In provisionally following the opinion of writers who adopted an opposite view, I always felt it to be a great difficulty how the resemblance between the limb-bones of the *Dermochelyidæ* and the *Chelonidæ* was to be explained if they had no direct affinity with one another.

I am glad to say, in conclusion, that Mr. Shrubsole has signified his intention of presenting the specimen under consideration to the National Collection.

* 'American Naturalist,' 1890, pp. 530 *et seq.*

## 4. *On certain* Ornithosaurian *and* Dinosaurian Remains. By R. Lydekker, Esq., B.A., F.G.S. (Read December 10, 1890.)

[Plate V.]

I may state, by way of introduction, that I am indebted to my friend Professor O. C. Marsh for the correct determination of the interesting reptilian bones forming the subject of the present communication.

### I. *Ornithosaurian Quadrates.*

When engaged in compiling Part I. of the 'British Museum Catalogue of Fossil Reptilia and Amphibia,' I was considerably puzzled with three imperfect bones from the Kimeridge Clay of Weymouth. Eventually I considered that they represented a peculiarly modified ulnar metacarpal of an Ornithosaurian; and they were accordingly entered at page 41 of the volume cited (Nos. 43034, 44183, and 41179) as the distal extremities of that bone. It was mentioned at page 40 of the same volume that these bones differed from normal specimens of the ulnar metacarpal in having a flat bony plate attached to one of their lateral surfaces, which I considered might have aided in the support of the patagium.

The resemblance of the free trochlear extremity of these bones to that of the distal extremity of the ulnar metacarpal of an Ornithosaurian is, indeed, very striking; but, on seeing them, Professor Marsh at once said that they were Ornithosaurian quadrates. On comparison with the quadrate of the skeleton of *Rhamphorhynchus Cuvieri* preserved in the Museum *, and also with that of *Scaphognathus Purdoni* † (acquired by the Museum since the first part of the 'Catalogue' was written), no possible doubt remained as to the correctness of this identification.

In Plate V. figs. 3 *a*, 3 *b*, 4 *a*, 4 *b*, views are given of two of these Ornithosaurian quadrates, one (No. 44183) belonging to a small, and the other (No. 41179) to a large form. From a comparison of these specimens with the quadrates of *Sphenodon*, *Rhamphorhynchus grandis*, and *Scaphognathus Purdoni*, it is quite evident that they belong to the right side of the skull. The distal extremity of each forms a deeply-grooved oblique trochlea, above which there is a nearly quadrangular shaft. To the inner side of this shaft is attached by suture a flattened plate of bone, concave internally and convex externally, which, from the analogy of *Sphenodon*, must evidently represent part of the pterygoid. In the larger specimen part of the anterior free border of the pterygoid is preserved in the upper part of the bone. To the outer surface of the distal trochlea of

* Catalogue, &c., p. 33. no. 37002.

† Phil. Trans. for 1888, pp. 503–537, pls. lxxvii, lxxviii.

these specimens it is evident that the quadrato-jugal must have been attached. By comparison with the skull of *Scaphognathus Purdoni*, it is evident that the smaller quadrate indicates an Ornithosaurian of the same approximate size as that species, while the other figured quadrate indicates a much larger form. These specimens show conclusively that the flat internal plate described in Mr. Newton's figures of the skull of *Scaphognathus Purdoni* as part of the quadrate, is really a portion of the pterygoid, and, consequently, that the relation of the quadrate to the pterygoid in the *Ornithosauria* is the same as in the *Rhynchocephalia*, and quite different from that obtaining in the recent *Crocodilia*, where those two bones are widely separated. So far as I can gather from the figures published by Professor Marsh, many Dinosaurs had the pterygoid ankylosed to the quadrate after the Rhynchocephalian and Ornithosaurian plan.

With regard to the species to which the specimens under consideration may have belonged, I find, by comparison with the above-mentioned skeleton of *Rhamphorhynchus grandis*, from the Lithographic Limestone, that the smaller quadrate would agree approximately in relative size with the so-called *Pterodactylus Manseli*, Owen, founded upon the distal portion of the humerus *. The larger quadrate would agree more nearly with the so-called *Pterodactylus supra-jurensis* of Sauvage †, founded upon a coracoid from the Kimeridgian of Boulogne; and, in the absence of any evidence to the contrary, I propose to refer it provisionally to that species. In the 'Catalogue' cited I stated that there was no evidence for referring *Pterodactylus Manseli* (and the allied or identical *P. Pleydelli*) to *Pterodactylus*; and from the large size of the specimens under consideration, and their marked resemblance to the quadrates of *Rhamphorhynchus grandis* and *Scaphognathus Purdoni*, I consider it probable that *Pterodactylus Manseli*, *P. Pleydelli*, and *P. supra-jurensis* are all three referable either to *Rhamphorhynchus* or *Scaphognathus*; and, since the former genus appears to be of commoner occurrence in the Lower Kimeridgian Lithographic Limestones than the latter, I am inclined to provisionally refer all three species to *Rhamphorhynchus*.

## II. *Vertebra and Tibia of a Cœluroid Dinosaur.*

In the 'Geological Magazine' ‡ I described two Dinosaurian vertebræ from the Wealden of the Isle of Wight under the name of *Calamospondylus Foxi*, being at that time unaware that the generic name had been previously suggested §, although without a definition, for the form subsequently described as *Aristosuchus pusillus*. Although the description of the original *Calamospondylus* is vague, it is undoubtedly a preoccupation of the name, and I accordingly

* See 'Catalogue,' &c., p. 40.
† Bull. Soc. Géol. France, sér. 3, vol. i. p. 375 (1873).
‡ Decade 3, vol. vi. p. 121 (1889).
§ Fox, Geol. Mag. decade 1, vol. iii. p. 383 (1866).

propose that *Calamospondylus Foxi* should henceforth be known as *Calamosaurus Foxi*.

These two associated vertebræ, which belong to the cervical region, indicate a Dinosaur referable to the Theropodous family *Cœluridæ*, all the members of which are characterized by the extremely pneumatic structure of the skeleton, as is especially shown by the cervical vertebræ. The cervicals of *Calamosaurus* differ from those of *Cœlurus* (represented in the Wealden by *C. Daviesi*) in being shorter, and also in that all were probably opisthocœlous, the middle and posterior cervicals of the type genus being amphicœlous *. Since the woodcut in which one of the vertebræ of *Calamosaurus* was figured in the original description is on a reduced scale, and is not altogether satisfactory, two views of this specimen are given of the full size in Plate V. figs. 1 *a*, 1 *b*. It may be mentioned that these vertebræ are of a characteristic brown colour, evidently indicating that they were obtained from a bed of the Wealden different from that which yielded the types of *Cœlurus Daviesi* and *Aristosuchus pusillus*, all of which are stained of a deep black colour.

Hitherto the above-mentioned vertebræ are all that have been known concerning *Calamosaurus*. During his recent visit to the Natural-History Museum Professor Marsh called my attention to the right tibia (B. M. No. R. 186) of a small Dinosaur obtained by the late Mr. Fox from the Wealden of the Isle of Wight, which has been incorrectly referred to *Hypsilophodon* †. This specimen was at once identified by my friend as referable to some member of the family *Cœluridæ*; and on careful examination it is at once seen to have nothing whatever to do with the *Iguanodontidæ*. This bone, of which two full-sized figures are given in Plate V. figs. 2 *a*, 2 *b*, is of the same brownish hue characteristic of the vertebræ of *Calamosaurus*, and was therefore probably derived from the same bed. Its total length is 6·1 inches. Its Theropodous characters are shown by the highly polished and dense nature of the outer surface, by the long and sharp fibular ridge (*f*) on the outer border ‡, by the extreme flattening of the distal half, and, above all, by the large facet at the distal extremity of the anterior surface (fig. 2 *a*, *as.*), for the articulation of the ascending process of the astragalus, the inner border of that facet terminating in a very sharp ridge. There is also the absence of the division of the distal extremity into two "steps." Where the specimen has been fractured the very large size of the central cavity may be seen.

It appears to me probable that this bone is of rather too small a size to have belonged to the same individual as that to which the

* In *Cœlophysis*, of the Trias of New Mexico, all the cervicals were amphicœlous.

† See 'Cat. Foss. Rept. & Amphib. Brit. Mus.' part i. p. 194. The whole of the four tibiæ mentioned on that page are referred to the wrong side; those marked right being left, and *vice versâ*.

‡ This is absent in the *Iguanodontidæ*; see Huxley, Quart. Journ. Geol. Soc. vol. xxvi. p. 19.

type vertebræ of *Calamosaurus Foxi* pertained; but, since it was obtained apparently from the same bed as the latter, there is a probability that it may have belonged to another individual of that species, to which I propose to refer it provisionally. Since *Cœlurus Daviesi* is still larger than the type *Calamosaurus Foxi*, it is unlikely that the present specimen belonged to that species.

In his description of the femur of *Megalosaurus*, Professor Huxley * commented upon its extremely bird-like form. These avian features are, however, still more intensified in the present specimen, which may be compared with the slightly smaller tibio-tarsus of *Apteryx Oweni*. The whole bone is relatively longer and more slender than the tibia of *Megalosaurus* †, its fibular ridge is much longer and more prominent, and the distal extremity is still more flattened. Even more remarkable is the great upward extension of the facet for the ascending splint of the astragalus, which reaches fully an inch up the shaft. The sharp ridge forming the inner border of the distal part of the surface for the astragalus corresponds to the ridge bordering the outer side of the extensor groove of the tibia of *Apteryx*, and thus still further intensifies the avian characters of the bone.

The present specimen is, indeed, the most bird-like Dinosaurian tibia that has come under my observation; and, in conclusion, attention may be directed to the very curious feature—that, whereas the *Ornithopoda* make the nearest approach to the avian plan of organization in the structure of the pelvis, it is among the *Theropoda*, so far as regards European types, that we find the most avian characters in the structure of the hind limb.

## EXPLANATION OF PLATE V.

Figs. 1 *a*, 1 *b*. Left lateral and anterior aspects of a cervical vertebra of *Calamosaurus Foxi*; from the Wealden of the Isle of Wight. *s*, neural spine; *prz*, prezygapophysis; *ptz*, postzygapophysis; *r*, cervical rib; *f*, pneumatic foramen.

Figs. 2 *a*, 2 *b*, 2 *c*. Anterior, distal, and posterior aspects of a right tibia referred to *Calamosaurus Foxi*; from the Wealden of the Isle of Wight. *a*, inner condyle; *b*, outer condyle (broken); *d*, cnemial crest; *f*, fibular ridge; *as*, facet for astragalus.

Figs. 3 *a*, 3 *b*. Posterior and distal aspects of the right quadrate of *Rhamphorhynchus Manseli*; from the Kimeridgian of Dorsetshire. *q*, quadrate; *pt*, pterygoid.

Figs. 4 *a*, 4 *b*. Posterior and distal aspects of a right quadrate referred to *Rhamphorhynchus supra-jurensis*; from the Kimeridgian of Dorsetshire.

All the figures are of the natural size.

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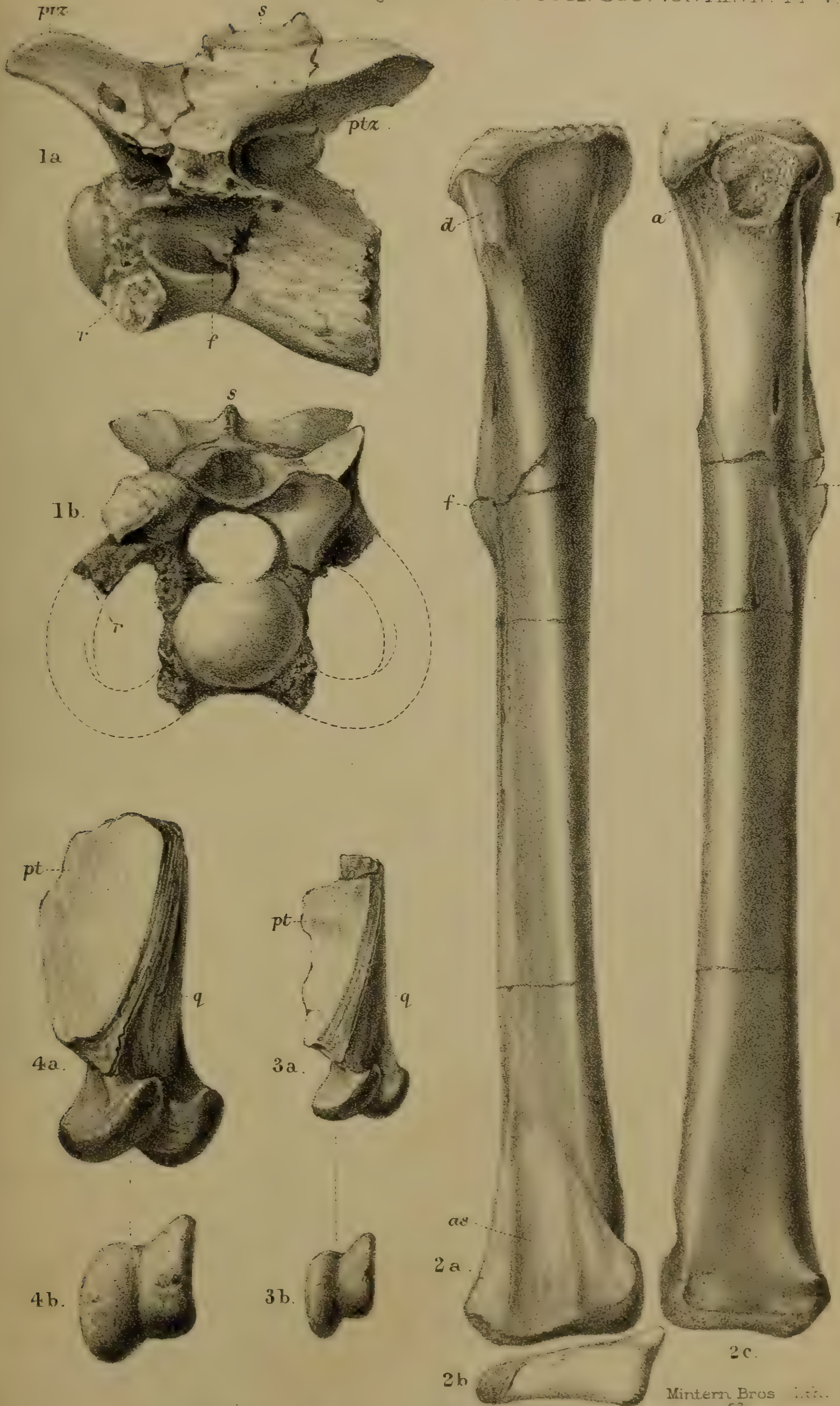
* Quart. Journ. Geol. Soc. vol. xxvi. p. 192 *et seq.*

† Huxley, *op. cit.* p. 20, fig. 1.




Mintern Bros. lith.

DINOSAURIAN & ORNITHOSAURIAN BONES.

## 5. *The* Variolitic Diabase *of the* Fichtelgebirge. By J. Walter Gregory, F.G.S., F.Z.S., of the British Museum (Nat. Hist.). (Read December 17, 1890.)

Contents.

I. Introduction.
II. General Features of the Surface.
III. The Variolitic Diabase.
IV. The "Pseudocrystallites."
V. The Relations of the Diabase.
VI. The Origin of the Variolitic Structure.
VII. Summary of Conclusions.

### I. Introduction.

Among the many interesting rocks described in 1874 by Prof. von Gümbel in his 'Die paläolithischen Eruptivgesteine des Fichtelgebirges' * was a variety of diabase crowded with small round, apparently felspathic bodies. As these stood out on weathered surfaces like peas or pearls, he suggested for it the name of "Perldiabas." Seeing that this peculiar modification occurred around the margins of the diabase masses, close to the contact with the sedimentary rocks into which they were intruded, Prof. von Gümbel regarded these pearl-like spheroids or "Knollchen" as fragments of the neighbouring beds caught up by the igneous rock, rounded by the rolling and the fusion of the sharp angles, and baked till they acquired the porcellanitic appearance that they now present. In the following year, Prof. von Zirkel, in his well-known paper "Die Structur der Variolite" †, described the microscopic structure of this rock, and, recognizing that the rounded spheroids are merely ordinary spherules, he identified it as variolite, and compared it with the typical varieties; he objected alike to von Gümbel's name and theory.

Prof. von Zirkel's conclusions were confirmed by Prof. Rosenbusch in his detailed microscopic examination of the rock ‡, and he, in accordance with the view taken by the French geologists of the origin of the Savoy variolites, regarded these also as ordinary "endomorphen Contactformen der Diabase" on the selvage of intrusive dykes.

Prof. von Gümbel's faith in his own theory stood firm against these criticisms and this new evidence; and in 1879, in the third volume of his great work on Bavaria §, he re-enunciated his hypo-

* P. 31; and N. Jahrb. 1876. pp. 42, 43.

† Berichte k. sächs. Gesell. Wissensch. vol. xxvii. (1875), pp. 209–220.

‡ 'Mikroskopische Physiographie der massigen Gesteine' (1877), pp. 358–366, and ed. 2, vol. ii. (1887), pp. 227–234.

§ 'Geognostische Beschreibung des Königreichs Bayern, Abth. iii. Geogn. Beschr. des Fichtelgebirges,' pp. 213–218. Gotha, 1879.

thesis, and supported it by a chemical and microscopic examination of the rocks; the criticism and works of both Prof. von Zirkel and Prof. Rosenbusch were, however, wholly ignored.

The two opposing theories had one point in common, viz. that they regarded variolite as the contact-product of a basic dyke with the rocks into which it is intrusive. In a paper "On the Variolitic Rocks of Mont Genèvre," published in this Journal *, it was shown that this, the generally accepted view, did not hold for the rock in its typical locality. The admirable description of M. F. Loewinson-Lessing † has shown that the same is the case with the less altered variolite of Yalguba. Prof. Dalmer's ‡ descriptions of the mode of occurrence of the Schönfels variolite in Saxony also suggest doubts as to the applicability of the older theory to that rock, since the diabase here seems to be variolitic throughout, as at Galgenberg, or at least to the extent of fifty yards from the contact-plane; this might, of course, be explained as due to subsequent intrusions of diabase into already consolidated masses, but there is nothing in Prof. Dalmer's description to show that this has occurred.

Such very various materials have been at different times included among the variolites that it seemed quite possible that the Fichtelgebirge varieties might have had a somewhat different origin. Hence it became advisable to examine some of the South-German localities of the rock, and compare its mode of occurrence at these with that of the Cottians and Liguria. For this purpose the district around Berneck seemed most suitable, as from it had been derived the varieties of which the microscopic structure had been so carefully described by Prof. Rosenbusch, and for which Prof. Gümbel's theory had been proposed.

## II. General Features of the Surface.

The little town of Berneck is picturesquely situated in the mouth of the valley of the Oelschnitz, at the north-east margin of the Fichtelgebirge. It extends from the confluence of the Oelschnitz with the Weisser Main, for about a kilometre up the deep and narrow valley which the former stream has cut through the great diabase massif to which this locality owes most of its geological interest. The diabase appears in the map of the Bavarian Oberbergamt (Blatt Münchberg, No. xi.) as covering an irregular triangle, about 4 kilometres long, with a base of some $2\frac{1}{2}$ kilometres. The area occupied by the diabase forms a high rugged plateau, divided into a series of "Leite" §, on the sides of which the best sections are to be seen; these are, however, never very satisfactory, as the

* G. A. J. Cole and J. W. Gregory, Quart. Journ. Geol. Soc. vol. xlvi. (1890), pp. 295–332.

† Tsch. Min. u. Petr. Mitth. vol. vi. (1884), pp. 281–300, pl. iv.; and "Olonetzkaya Diabazovaya Formatziya," Trudui St.-Peterburgskagho Obshch. Estest. xviii. (1888), pp. 165–169.

‡ Erläuterungen zur geol. Specialkarte des K. Sachsens. Section Planitz-Ebersbrunn; Bl. 124, pp. 25. Leipzig, 1885.

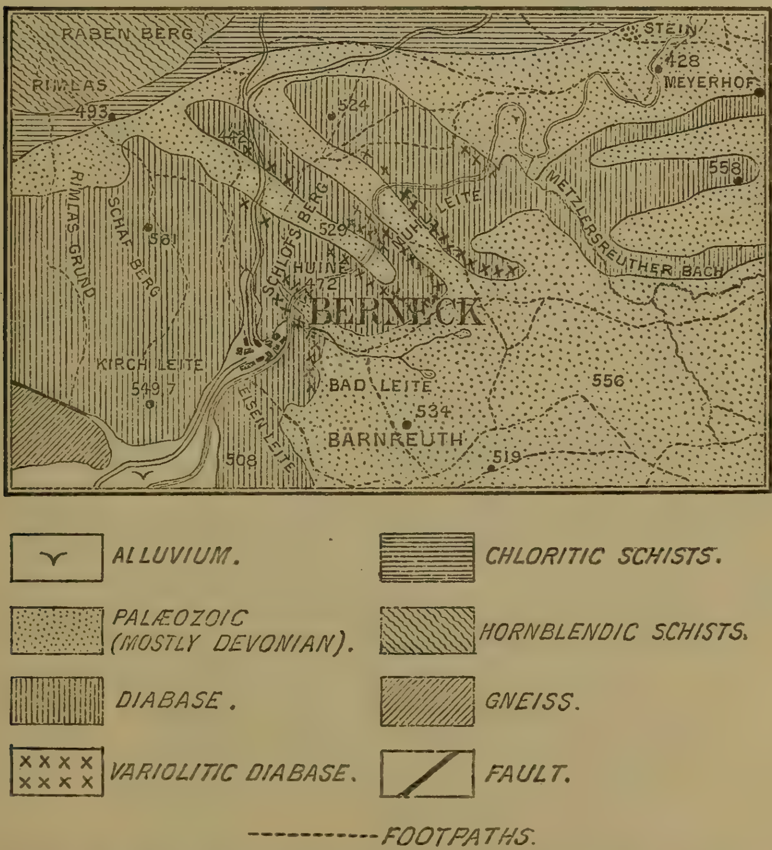
§ This is a *provincial* word, meaning "place," whether plateau, slope, crest, or even valley.

junctions of the diabase and the Devonians are, as a rule, hidden either by dense fir-forest or talus.

The diabase is bounded on the north-east and south by narrow bands of Devonian and Lower Palæozoic rocks, including some chloritic schists and phyllites; these run from S.W. to N.E., extending up the valley from Berneck to Metzlersreuth, Zell, and Sparnack. The strike of the rocks is generally parallel to that of the valley, but they have been greatly contorted, and sometimes inverted, by the earth-movements which squeeze them in between the Münchberg gneiss plateau on the north, and the granitic and gneissose area of the Fichtelgebirge on the south.

Prof. von Gümbel's map is here very diagrammatic, and in many cases the lines of the outcrop of the diabase are very different from those on the accompanying sketch-map, which is on a larger scale. The floor of the valley along which runs the path from Berneck to

Fig. 1.—*Sketch-map showing the Distribution of the Variolitic Diabase, near Berneck, Fichtelgebirge, Bavaria.*




Heinersreuth, the lower parts of the wooded slopes of the south bank of the Oelschnitz opposite Stein, much of the meadow-land south of Meyerhof and of the fields that run up into the Mühlleite are occupied by the shales, grits, and slates of the Devonian, instead of diabase, as is shown on von Gümbel's map.

### III. The Variolitic Diabase.

At the north-east end of the town of Berneck, just above the uppermost bridge over the Oelschnitz, is a boss of spheroidal variolitic diabase; it is situated in the angle between the path that runs beside the river to the "Colonnade" and that which traverses the valley between the Badleite and the Mühlleite. Beside the former path there is an excellent section some 65 yards long. The main mass of the diabase is a close-grained decomposed aphanite, jointed into spheroids, which vary in diameter from 80 millim. to more than a metre. The diabase of the spheroids is compact both in the centre and on the periphery, but at a little distance from this, and running parallel to it, is a band of variolite; the varioles in the centre of this band are usually from 2 to 3 millim. in diameter, but on each side they gradually decrease in size and number, so that it passes into the compact normal diabase. Thus, to quote the figures in one case,—externally there is a layer of compact diabase 30 millim. thick; then a 50 millim. layer of variolite, and within a mass of the aphanite 120 millim. across; below there is the same 50 millim. of the variolitic, and 30 millim. of the compact diabase.

Fig. 2.—*Section of Variolitic Spheroidal Diabase. Footpath to the Colonnade, Berneck.*


Some of the smallest of the spheroids, however, are variolitic throughout. When examined under the microscope with a low power, the rock is seen to consist of a thick green groundmass, containing a number of round white varioles, sharply marked off from the groundmass. In both occur small circular vesicles filled

with chlorite, and a large number of irregular spaces of a slightly dichroic, transparent material. Under a higher power, though the rock is greatly decayed, the principal points in structure can be determined. The groundmass is resolved into three constituents: there is a greenish, isotropic matrix, the transparency of which is diminished by a dust of minute opaque grains; it also contains a crowd of small granules and crystals; in most cases these are certainly augite, and it is probable the whole series are of this mineral. Occasionally a few fine felspar needles occur in the groundmass, and sometimes these are grouped into radial clusters. The small irregular rifts and spaces come out very prominently, owing to the transparency of the mineral that fills them; this is sometimes slightly dichroic and polysynthetically twinned, and shows a strong tendency to crystallize in rhomboidal forms. These characters show that it is dolomite, and it is obviously secondary in origin; most of the smaller lines, however, are only singly refracting, and in this material occur numerous small inclusions. These structures must be compared with the "pseudocrystallites" described and figured by M. Michel-Lévy, and further reference will be made to them in a later section of the paper.

The varioles in this rock belong to the variety with radial structure and sharply marked off from the matrix: they thus differ from those figured by von Gümbel * from the opposite side of the Oelschnitz. The outer layer of the varioles is greatly altered and decomposed, and, while the minerals themselves have been destroyed, the external margin has been corroded. Internally they consist of a large number of small, radiating, and often branching fibres of a grey mineral, which is certainly a plagioclase, and apparently oligoclase; intercalated between these are granules of augite, similar to those that are scattered through the groundmass. The varioles are of the compound radial type. Fig. 3 (p. 50) shows one with the plagioclase needles radiating from several centres, while around the margin are several smaller secondary varioles.

The extensive alteration that the rock has undergone, indicated both under the microscope and in the rock by the calcareous veins that traverse the diabase, does not encourage one to expect much assistance from chemical analysis. Prof. von Gümbel gave analyses of the groundmass and varioles † ; that of the latter is the more interesting, but it really does not help much:—

| | |
|---|---|
| Silica | 64·33 |
| Alumina | 13·46 |
| Oxide of iron | 8·29 |
| Lime | 4·63 |
| Magnesia | 1·58 |
| Potash | 1·75 |
| Soda | 5·36 |
| | 99·40 |

* Geogn. Beschr. Fichtelgebirg. fig. 31. † *Ibid.* p. 217.

The paucity of alkaline earths and alumina renders it difficult to see what combination of oligoclase and augite could give such an analysis, especially when we have to deduct a little lime and magnesia for the secondary products in the interspaces. The history of this analysis, however, does not dispose one to place much confidence in it, and, with such intensely altered rocks, the microscope is probably a safer guide than the chemical balance.

Fig. 3.—*Section of the variolitic Diabase, with a large variole; from the pathway to the Colonnade, Berneck. Some Pseudocrystallites occur in the lower part of the figure.* $(\times \frac{34}{\frac{2}{3}}$.—N.B. The numerator represents the original magnification, and the denominator the reduction from the size of the field of the microscope.)

The microscopic examination, however, fully proves the identity of this rock with that of Mont Genèvre, though, being older, it has undergone greater alteration; the pea-shaped bodies or "Knollchen" are shown to be true varioles, composed of a mixture of felspar fibres and augite granules and needles similar to that which occurs in the typical variety from the Cottian Alps.

Here, then, in this boss of diabase we have the variolite of the Fichtelgebirge; but, instead of being a mere contact-product developed at the junction of the diabase and the rocks into which it is intrusive, it occurs in the centre of the igneous rock, at some places at least fifty yards from any other rock. According to von Gümbel's map this knoll is in the middle of the diabase area; but on the opposite slope of the Oelschnitzthal there may be seen, sandwiched between coarse ribs of diabase, some smooth slopes that indicate the presence of the Devonian *. Pebbles of the same formation may be picked up in the gully on the south side of the knoll up which the path rises from the foot-bridge; and a few yards

* These are shown in the woodcut by Prof. von Gümbel, *op. cit.* p. 525.

along the footpath to Heinersreuth the sedimentary rocks may be seen *in sitû*. Hence the diabase was probably close in contact with a band of Devonian, which now crosses the stream obliquely at this point; so, though the variolitic spheroids are in one place no less than sixty yards from the Devonian horizontally, they may have been nearer to it vertically.

The gully up which the path rises from the bridge, the river, and a pine-covered slope completely obscure the junction of this mass of spheroidal diabase with the adjacent beds; hence one turns to the neighbouring Devonians to follow the margin of their outcrop in the hope of finding a section elsewhere.

The pathway that goes east to Heinersreuth is at first bounded to the south by steep crags of diabase, while to the north there is a more gentle fir-covered slope in which occasional exposures of the same amygdaloidal diabase are to be seen. The south margin of the Devonian crosses the brook that drains the valley and winds up the slope of the Badleite, at first roughly skirting the wood; after one or two sharp bends, it turns abruptly to the south, and the Devonians are soon succeeded by the Silurians and Cambrians which rise from beneath them and abut against the diabase. There are no clear sections of the junction, but in a few places the diabase close by it can be seen; in such cases it is somewhat variolitic, though in places the amygdules that also occur obscure the varioles. Returning to the north side of the valley, an outcrop of Devonian in the bed of the stream enables one to get better acquainted with one important member of this formation—a coarse grit composed of fragments of quartz, quartz-mosaic, micropegmatite, and worn cleavage fragments of plagioclase; by the increase in the amount of the fine matrix that frequently occurs between the grains, and the decrease in the size of the coarser constituents, the rock passes into a shale; it is comparatively unaltered, except for a tendency to cleavage.

Along the north slope of the valley the junction of the diabase and Devonian is buried in fir-woods; occasionally there is a limited outcrop of an amygdaloidal diabase overlain by a thin-bedded shale. The sections are, however, rather unsatisfactory. A little less than a kilometre along the valley the Devonians project into the diabase and run up the slope to the summit of the Mühlleite; they occupy a slight depression, which at the south end is 100 yards wide. Patches of variolitic diabase occur along the junction, and weathered lumps of it are common upon the surface at the foot of the bank of diabase that bounds the Devonian. The variolite is best seen, *in sitû*, in a tree-covered ridge that forms the eastern boundary of the field occupied by the Devonian shales; a larger section is exposed in a knoll at the end of this ridge, which overhangs the path to Heinersreuth. The section is as follows, in descending order:—

1. Massive-jointed and bedded grit (dip 30° to N., 25° W., magnetic), 15 feet.

2. A thin-bedded finely-jointed shale, with some calcareous nodules and quartz veins; along its lower margin it is somewhat baked and in places brecciated.
3. An amygdaloidal diabase, cutting irregularly across the edges of the shale, which are sometimes curved up along the junction. The exposed surface of the diabase is sometimes variolitic.

Fig. 4.—*Junction of Variolitic Diabase and Black Shales; in the Crag, north of the pathway to Heinersreuth.*


Beds 1 and 2 belong to the Middle Devonian, and apparently to the lower part of this division (the "Unterschalstein mit Kalkgeoden" of Gümbel). The Lower Devonian can be seen lower down the slope, and especially at a pit in the "Nereïtenschiefer" in the meadow where the brook that drains the upper part of this valley takes its source.

The interpretation of this section appears to be somewhat as follows:—A tongue from the diabase massif has projected for some distance into the Devonian rocks, running approximately E.S.E., and forming a ridge that extends as far as the Heinersreuth footpath. The face of the intrusive diabase has been here exposed by removal of the grits and shales during the denudation of the valley.

The microscopic structure of this variolite must be compared with that of the spheroidal knoll at Berneck. The rock consists of a series of altered varioles in a transparent, light-green, slightly

dichroic groundmass. An examination with higher magnification shows in this chloropitic groundmass numerous scattered, opaque white granules and large numbers of minute needles of actinolite; the former frequently occur in lines which curve round the varioles. The varioles themselves are so much altered that their original structure cannot be fully determined. The resemblance of the alteration-products to those of the variolite already described suggests a community of composition. The varioles are now an opaque dusty mass charged with lines of granules and needles of ilmenite, while in places there are transparent areas of a dolomitic mineral traversed by numerous needles of apatite. The opaque dusty material is probably a kaolin resulting from the decomposition of the felspathic microliths or globulites, while the dolomite and ilmenite are the products of the alteration of the pyroxene. The true radial arrangement of the Berneck varioles is absent, and the only approach to it is due to the disposition of the secondary ilmenite needles. The whole structure of these spherulites shows that they are more primitive than the others, and due to a more rapid and imperfect development.

Returning along the south side of the tongue of diabase we can trace the junction with the Devonians across the crag already described, and beside the tree-covered bank that separates two fields of shale and grits, to the summit of the Mühlleite. Just on the brow of the hill a brecciated limestone crops out across the field, and is succeeded by beds of shale with calcareous nodules (Middle Devonian). This series of sedimentary rocks can be traced away to the north-west down the steep slope to the Oelschnitz, across the stream, and up the opposite bank. It forms a slight depression, bounded on each side by a rib of diabase; that on the north-east side of the Devonians is the more conspicuous, but that on the south-west is spheroidal in one place, a few feet from the junction. A section through this has been cut in making a wood-cutters' road, which ends abruptly on the Devonian band. The diabase is less amygdaloidal, and is more regularly variolitic, than when in immediate contact with the clastic deposits. Along the line of junction the influence of contact-alteration can be seen in the Devonians; the shales are indurated, baked, and iron-stained, and the limestone brecciated and marmorized.

The same contact-phenomena, both in the development of a variolitic structure and the alteration in the sedimentary deposits, can be seen round a similar tongue of diabase that projects from the Mühlleite a little further to the north-west, and runs for some distance towards the south-east into the Devonian.

Except for an occasional band of Devonian that stretches across the ridge, the whole of the south bank of the Oelschnitz and the Metzlersreutherbach in this area is of the ordinary amygdaloidal diabase.

Having descended from the Mühlleite to the Oelschnitz, one turns to the steep left bank of this river in the hopes of finding a better section than the few scrappy exposures previously noticed.

A dense fir-forest, however, clothes the whole slope and prevents any very satisfactory evidence being obtained. Nevertheless, here and there a knob of rock rises above the soil of pine-needles, the path beside the stream shows an occasional low section, and the bed of the stream affords a little additional information as to the general nature of the diabase and its varieties. The principal types are: (1) a compact non-vesicular diabase; (2) a weathered amygdaloidal diabase; (3) the variolitic diabase, and this is usually associated with spheroidal varieties.

The compact diabase varies considerably in coarseness: some is quite microcrystalline, some is full of delicate acicular crystals of felspar; while in other places it is very coarse, as at about 80 yards on the Berneck side of the drinking-fountain. One of the most interesting varieties of this group of diabases may be seen crossing the Metzlersreutherbach at the south end of the meadow which stretches from the Oelschnitz up the course of its tributary. This rock stands out from the slopes on either side as a dyke-like wall that forces the stream into a small cascade. The rock is much altered; zoisite has been extensively developed in the plagioclase, and the whole of the pyroxene has been converted into a dichroic, chloritic, greenish mass; the most marked feature in this—as in most of these compact diabases—is the great abundance of leucoxene, resulting from the alteration of ilmenite. Though the specific gravity of this rock is high, and it probably originally contained an excess of iron in the form of primary ilmenite, no doubt most of this was secondary, and produced as a result of the decomposition of the augite. Specimens can be collected which are quite white from the great abundance of the leucoxene.

The compact diabases are, however, rather exceptional, and the weathered amygdaloidal varieties occupy the largest part of the area. The commonest type of this is a rock with a bright green, strongly dichroic matrix, crowded with actinolite needles and grains of leucoxene; some of the latter still retain part of the original ilmenite. The vesicles are mainly filled with calcite, but some zeolites are present.

The sections are so scrappy that the relations of the two classes of diabase cannot be accurately determined. It is possible that some of the compact diabase may be in the form of dykes intrusive into the amygdaloid, but in several cases a gradual passage between the two can certainly be traced. The relations of the normal and variolitic diabases to one another, and of both to the Devonians, is, however, clearly shown at several places along the Mühlleite. Two large and several small bands of the Devonians can be seen in the bed of the Oelschnitz and traced up the banks on each side; tongues of the diabase may be seen intrusive into these. One of the best cases is a short section cut by the lower path, in which a bed of lydianstone, a baked shale, is irregularly overlain by the amygdaloidal diabase, and in this is a band of still more altered Devonian. Microscopic examination of this rock shows that it was once a shale with a few layers of grit, and that it

has been crushed and minutely faulted. This case is further of interest as there is no variolite along the contact with the Devonian.

An equally clear section occurs in a small quarry in line with the waggon-ford that crosses the stream just above the second foot-bridge. The section is composed of a mass of spheroidal variolitic diabase, and across it runs a band of baked shale which thins towards, and forks at, the lower and north end. Here, again, the diabase is neither variolitic nor spheroidal at the actual contact with the shale, but acquires these structures at about one foot from it.

Fig. 5.—*Section of the normal compact Diabase from the Oelschnitz-thal, with a vacuole filled with chlorite.* ( $\times \frac{80}{\frac{2}{3}}$. See p. 50.)

The junctions of this diabase and the neighbouring Devonians are obscured, but the latter occur in mass a few yards away.

It is unnecessary to trace the junctions of the diabase and the Devonians further through the area. On the opposite side of the Metzlersreutherbach, in the bank of the same stream near Heinersreuth, in the wood south of Meyerhof, and in other places, the same features are repeated. The relations of the diabase to the eye-gneiss S.W. of Berneck are, however, worth consideration; the junction can be seen in the road that rises steeply up the west bank of the valley which leads to Micheldorf, a little south of the quarry. The two rocks are certainly faulted against one another, and hence we search in vain in the crushed and brecciated diabase for any trace of the variolite.

The evidence adduced is sufficient to show, at least in the case of the area south of the Oelschnitz and the Metzlersreutherbach, that, though the variolite does occur along the line of the junction of the Devonian and the diabase, when it appears as a true contact-selvage, the varioles are not well developed, and usually lack the radial structure. Further, that it is only in the compact, or but slightly vesicular, spheroidal diabase, usually at some little distance from the actual plane of contact, that the sharply-marked radial

varioles are typically developed. I did not myself have the good fortune to obtain from the area specimens of all the types of variolitic structure described by Prof. Rosenbusch from Berneck; but it is probable that a more careful examination, especially to the north of the Oelschnitz, would show that they may be all grouped into the two classes—of those that are true contact-selvage-products and those formed within the diabase. No doubt occasionally a more perfect variole may be found among the former, and a rudimentary one among the latter, but as a rule this division will probably be found to hold.

## IV. The "Pseudocrystallites."

In the course of M. Michel-Lévy's admirable description * of the microscopic structure of the Mont Genèvre variolite, he described and discussed the nature of certain enclosures in the varioles which he named "pseudocrystallites." In the previously published description of the fine plate † in the 'Minéralogie Micrographique,' MM. Fouqué and Michel-Lévy attributed these bodies to "fissures of retreat;" but in the latter author's more detailed subsequent examination he was led by the peculiar optical properties of these structures to regard them as felspathic pseudocrystallites. He observed that when their long axes are parallel to the neighbouring felspar fibres they extinguish at once throughout their entire length, but when they traverse the radial fibres they disappear under crossed nicols, as the felspars seem continuous across them; hence M. Michel-Lévy was forced to regard such pseudocrystallites as composed of a complex aggregate of felspar crystals, differently orientated, so that their long axes were in the same straight line as those of the radiating felspar fibres of the variole. As it did not seem easy to see how such an arrangement should have taken place if the felspar in these bodies were a secondary product, M. Michel-Lévy was led to this modification of the earlier theory.

In the paper by Mr. Cole and myself, we were led, by noticing how the larger rectangular fissures passed off into the minute branching irregular cracks, to regard them as due to rifts formed during contraction, but we could offer no explanation of the abnormal optical properties or arrangement of the felspathic constituents. We concluded ‡ that they were "little fissures due to fracture or contraction," and that "until a similar structure is found in other rocks, so that ample comparison may be made, the last word cannot be said on these interesting 'pseudocrystallites.'"

At Berneck there is a great development of these structures throughout the whole rock; they frequently occur in great numbers in bands which pass through variolite and groundmass alike, while

* "Mémoire sur la variolite de la Durance," Bull. Soc. géol. France, 3me sér. vol. v. (1877), p. 238.

† Pl. xxiv. fig. 2.

‡ Quart. Journ. Geol. Soc. vol. xlvi. (1890), pp. 313 & 314.

the individual pseudocrystallites can often be traced from the one into the other. There seems no reason to doubt the identity of these bodies with those at Mont Genèvre; the difference between them is only in the infilling material. At Berneck the rock is permeated with calcareous infiltration-products which line the joints and form veins that cross the spheroids; hence the pseudo-crystallites are mainly filled with calcareous or dolomitic products: but at Mont Genèvre the veins and cracks are mainly occupied by felspathic material, and hence these rifts often contain plagioclase fibres. At Berneck the secondary material in the spaces is quite different from that which forms the rock on either side; they are therefore sharply marked off from it in any condition of illumination. At Mont Genèvre, on the other hand, not only is the material that has filled up the rifts similar to that of the surrounding rock, but the felspar has been deposited in optical continuity with the crystalline fibres that were broken and separated by the formation of the pseudocrystallite. Such cases of the restoration of the optical continuity of crystals across cracks by the deposition of secondary minerals in the latter appear to have been fully established *. If this suggestion be accepted, it would supply a very striking and complex case of this phenomenon, while it would also afford a full explanation of the abnormal optical properties that M. Michel-Lévy has described in these structures.

It appears to have been these optical characters almost entirely that led M. Michel-Lévy to his theory of the origin of the "pseudo-crystallites"; apart from these, and though in many cases it must be admitted that the regular reticulation of these structures does present the aspect of a crystalline meshwork, the evidence in favour of the origin of these bodies as cracks and fractures subsequent to consolidation seems fairly conclusive. This view is supported by their irregular distribution, both in the varioles and the groundmass, well shown in specimens from Berneck, by the gradual transition that can frequently be traced from them into undoubted cracks, and by the fact that they sometimes pass from a variole into the groundmass. The freshness of the material is an additional argument, and apparently this alone was sufficient to induce Prof. von Gümbel to consider them as secondary.

As first figured by MM. Fouqué and Michel-Lévy, there was a certain regularity in the disposition of these cracks, as they occurred along a zone arranged concentrically with the variole; in this case the variole is sharply marked off from the groundmass, and no doubt the shrinkage that caused this distinct separation found out a line of weakness due to one of the concentric zones of glassy matter that often occur in spherulites. Iddings † has figured a spherulite in which a number of trichites are disposed in a similar circle to that in this variole. Where, however, the spherulite passes gradually

* See, for example, the cases figured in this Journal by Miss Raisin, vol. xlv. p. 253, and by Cole and Gregory, vol. xlvi. pl. xiii. fig. 1.

† J. P. Iddings "Obsidian Cliff;" 7th Ann. Rep. U.S. Geol. Surv., Washington, 1888, p. 276, pl. xv. fig. 4.

into the glass, as in many of the Fichtelgebirge variolites, the contraction due to the segregation of its constituents has not tended to the production of concentric cracks, but of some which are either irregular or parallel to any structural planes, such as lines of flow, that there may have been in the rock: these primary fissures would of course be connected by cross cracks; thus would arise such a reticulate series as is shown by Prof. von Gümbel *.

## V. The Relations of the Diabase.

In Prof. von Gümbel's description clear evidence is given of the intrusive nature of the diabase into the Devonian. The long rib-like dykes below the Schloss, the baked shales and marmorized brecciated limestones of the Mühlleite, the irregular nature of the junction, with the long tongues of the diabase running out into the Devonian, the inclusions of the baked sedimentary rocks, and the absence of tuffs, leave no doubt as to the truth of this view †. In connection with the last point, however, it is necessary to examine the grit-like rock found at the crag by the path to Heinersreuth, and a similar rock with large shale fragments on the south bank of the Oelschnitz opposite Stein, which are no doubt the schalsteins mentioned by von Gümbel. The latter rock is well exposed in a couple of ribs of rock running down the steep slopes of the bank of the river; it has a coarse gritty matrix, charged with large angular fragments of shale. Microscopic examination entirely dispels the idea that it is a true tuff; it has, however, been made up almost entirely by the decomposition of igneous and volcanic rocks, and thus chemically, and at first sight microscopically, resembles a tuff. The matrix of the rock is composed of fragments of a fine-grained diabase, rolled cleavage-fragments of plagioclase, and fragments of quartz and quartz-mosaic, &c.; in addition there is a good deal of quartz with a remarkably well-developed micropegmatitic structure. The same constituents, but without the coarse shale fragments, occur in the grit of the crag. In both cases the fragments are mostly somewhat rounded and water-worn, and the rocks are no doubt true grits, the materials of which have been derived from the denudation of an area containing such rocks as those which form the highlands of the Fichtelgebirge to the south, or of the Münchberg gneiss massif to the north; in the latter Prof. von Gümbel has described a micropegmatite very similar to that which is so striking a feature in these grits.

As to the date of the intrusion but little can be said. The diabase can be seen intrusive into the Lower Devonian on the flanks of the Badleite, into the Middle Devonian on the Mühlleite, and into the Upper Devonian in several places along the right bank of the

* Geogn. Beschr. Fichtelgebirg. fig. 31.

† Brauns has recently described a variolite forming a crust over a diabase-lava stream at Homertshausen: "Mineralien und Gesteine aus dem hessischen Hinterland," Part ii. Section 4; Zeitschr. deut. geol. Gesellsch. vol. xli. (1890), pp. 502–532.

Oelschnitz, as at Berneck and near Stein. This gives us a maximum age. The intrusion was apparently before the great earth-movements in which the band of Palæozoic sediments that now occupies the valley from Berneck through Gefrees and Sparneck to Schwarzenbach was squeezed in between the Münchberg gneiss and the igneous rocks of the Fichtelgebirge.

The normal strike of the Devonian was no doubt originally parallel to that of the Silurian and Cambrian and to the valley; but the mass of the hard diabase has resisted compression better than the more yielding sediments, and these have been bent round the diabase until their strike is often very oblique to their original direction. Further, the fact that the diabase is faulted against the gneiss on the other side of the Oelschnitz suggests that the diabase was consolidated before the great earth-movements took place which impressed upon this area its principal features.

## VI. The Origin of the Variolitic Structure.

In this examination of the diabase to the south of the Oelschnitz we have seen that the variolite in a more or less perfect form constantly tends to appear along the lines of contact with the neighbouring rocks, or where the diabase becomes spheroidal. It was this relation of the variolite to the neighbouring deposits, and a certain resemblance of the varioles to the baked shales, that led Prof. von Gümbel to the theory that these bodies were fragments of the Devonian rocks caught up at the time of intrusion. The detailed microscopic descriptions by Prof. Rosenbusch clearly demonstrate that, except possibly in one case, the varioles are true spherulites. Nevertheless, as Prof. von Gümbel has again stated his theory in his latest work *, it may be worth while to note what light is thrown upon it by field work. Included fragments of the neighbouring shales in the diabase do occur, as is shown by a good specimen in the Heidelberg Museum; but, though baked, these have no resemblance to the true varioles. In all cases in which the varioles were formed of more than mere globulitic accumulations, or which are sufficiently well preserved for their original constituents to be determined, they consist of plagioclase needles, ilmenite, and pyroxene; the baked schists may be sericitic and chloritic, but the above minerals have not been developed. Moreover, the occurrence of the varioles in bands parallel to and at a little distance from the circumference of the spheroids, their regularity, and the gradual passage of the variolitic into the normal compact diabase by the diminution in size and number of the varioles, are features which cannot be satisfactorily explained on Prof. von Gümbel's hypothesis. In some cases there seems to have been some confusion, here as elsewhere, between the true variolites and the pseudovariolites or spilites. It is sometimes not easy, without the aid of the microscope, to distinguish between the variolite and some of the weathering amyg-

* 'Geologie von Bayern,' Th. i. Lf. 1 (1884), pp. 78, 79.

daloids. Prof. von Gümbel has described * the diabase sheets of the Labyrinthenberg as coated with variolite; but, though I hammered carefully over the whole section, I could find no true variolite, but plenty of an amygdaloid that somewhat closely resembled it †.

Though the variolite is thus shown to be a true endomorphic alteration-product, and due, no doubt, to contraction during a somewhat rapid cooling, the view that it is an ordinary contact-selvage is not fully adequate, as frequently around some of the Devonian masses in the Mühlleite no variolite occurs at the junction. It is only where the diabase is at the same time spheroidal that the variolitic structure has been fully produced. In the Fichtelgebirge, as at Mont Genèvre and in Saxony, the variolite mainly occurs, not as a contact-alteration-product along the junctions of the diabase and other rocks, but on the surfaces of great diabasic spheroids. At Mont Genèvre, in one or two places, a thin spherulite film does occur along the margins of the diabase dykes, but this is rare and always minute. Similarly, in this locality, where the variolite occurs as a contact-product it is thin and inconspicuous, and the varioles are less perfectly developed. In such cases the solidification has apparently been too sudden to allow of the segregation of the felspathic and pyroxenic constituents into spherulites. The variolitic structure has been due to rapid cooling, but is of a less extreme type than that which has produced the amorphous glass of normal basic selvages.

These considerations further suggest the explanation of the rarity of the variolitic amygdaloid, as compared with the compact varieties of the rock. When, owing to diminished pressure or other cause, the solidifying diabase became vesicular by the explosion of its water into steam, the amount of water in the molten magma would be lessened; this would consequently become less fluid, and the solidification of the rock be further hastened.

That the variolite appears most perfectly in association with spheroidal masses is quite natural if we regard the latter structure as due to processes of contraction during solidification, as shown by Prof. Bonney in his well-known paper ‡.

The diabase in this knoll, rapidly cooling by the conduction of its heat to the neighbouring rocks, contracted into great spheroids, which, while semiviscid on the periphery, were still fluid within; under the pressure of the forces that drove them upwards, these rolled over one another and were drawn out into oval masses. It was during this process that the felspathic and pyroxenic constituents

* Geogn. Beschr. Fichtelg. p. 483.

† Nor did there seem to be any variolite from this locality in the Museum of the Bavarian Oberbergamt in Munich. This collection contains specimens from several of the other localities mentioned by Prof. von Gümbel, and these are certainly true variolites, as, *e. g.*, from Steinbach. For the opportunity of examining the collection there I must express my thanks to Dr. L. von Ammon.

‡ T. G. Bonney, "On Columnar, Fissile, and Spheroidal Structure," Quart. Journ. Geol. Soc. vol. xxxii. (1876), pp. 140–154.

began to crystallize out around various points; the plagioclase needles forming radiating clusters, between which the augite granules were wedged in; as these half-formed varioles were rolled over, still other layers of the variolitic constituents were deposited around them; when the varioles were originally in close contact, these later layers enclosed several and built up the compound varioles.

The close connection of the typical variolite with spheroidal structure, which is the case in the Alps, in Italy, in Saxony, and in Wales, reminds one of the recent theory of Prof. de Stefani *, attributing the formation of the varioles to secondary decomposition in the outer layer of diabase spheroids. In fact, just as Thomson and other early authorities regarded the spheroidal structure itself as due to weathering, Prof. de Stefani considers these spherulites as due to the same cause. But this theory of the formation of the great spheroids has been generally abandoned since Prof. Bonney's paper on the subject; while the objections to this hypothesis are still more weighty when it is applied to these smaller structures. The fact that the varioles often occur, not on the extreme edge of the spheroids, but often 20 to 30 mm. from it, in rock which is comparatively unaltered, while, where decomposition has gone on along cracks or fissures, it has not produced any such structure, would be conclusive evidence against this view, even were not the analogy between these Palæozoic varioles and the spherulites of recent lavas sufficiently exact to demonstrate their community of origin.

## VII. Summary of Conclusions.

1. That the variolitic diabase of Berneck, which may be taken as a type of those of the Fichtelgebirge, is intrusive into the Devonian.

2. That the variolitic structure occurs in two different arrangements:—

   (*a*) On the surfaces of spheroidal masses of compact diabase, which are comparable to those of the eruptive rock of Mont Genèvre.

   (*b*) As a true contact-product on the selvage of the diabase.

The latter are comparatively rare, and the varioles less perfectly developed.

3. That the varioles are true spherulites, and not included fragments of the Devonian rocks.

4. That, though the varioles be the product of rapid cooling, too sudden a solidification of the diabase may prevent their formation.

5. For a similar reason the amygdaloidal is less variolitic than the compact diabase, the loss of the water that occupied the vesicles having diminished the fluidity of the rock.

6. That the "pseudocrystallites" are rifts and fissures due to contraction; and that the remarkable optical properties described by M. Michel-Lévy are due to the filling-up of cracks by felspathic

* C. de Stefani, "Le rocce eruttive dell' Eocene superiore nell' Apennino," Boll. Soc. geol. Ital. vol. viii. no. 2 (1889), 1890, p. 223.

matter deposited in optical continuity with the crystalline fibres on either side.

7. In regard to the terms used, it should be explained that the word *diabase* has been retained in Hausmann's sense; most of this rock, however, is more strictly an augite-porphyrite, probably resulting from the alteration of an augite-andesite. The varioles have been throughout referred to as *spherulites*, from the belief that the variations in structure which place them among the "pseudo-spherulites" of Prof. Rosenbusch are due solely to secondary alterations.

## 6. *On some* Water-worn *and* Pebble-worn Stones *taken from the* Apron *of the* Holt-Fleet Weir *on the* River Severn. By Henry John Marten, Esq., M.Inst.C.E., F.G.S., Engineer to the Severn Commissioners. (Read December 10, 1890.)

In the year 1844 a weir was constructed by the Severn Commissioners across the River Severn at a place called Holt Fleet, about eight miles above the city of Worcester, with the object of impounding the water above it, for navigation purposes, to a height of 5 feet 4 inches above previous low summer-level.

The weir, a plan and section of which accompany this paper (figs. 7 & 8), is a dam of solid masonry across the river, without any sluices in it; so that the whole of the water passing down the river at that point flows over the crest of the weir and down the slope, or face of the apron, on its lower side.

The crest of the weir is 300 feet in length, and the drainage from 1870 square miles (nearly 1,200,000 acres) of country above it, extending to the Plinlimmon range, is discharged over it.

The stones of which the weir is constructed were taken from an adjoining quarry at Holt Fleet, and consist of a soft red sandstone of the Upper New-Red-Sandstone Formation, marked F. 5 on the one-inch map of the Geological Ordnance Survey.

In the year 1887, or 43 years after the stones were placed on the apron of the weir, an examination was made of them, as some of the stones had become displaced and others showed signs of decay.

The examination brought to light the fact that a large proportion of the stones on the Island side of the central portion of the apron of the weir had been drilled through and through by the action of the current upon small pebbles lodged either in hollows on their exposed surfaces, or between the joints of the stones *.

A table is appended (page 67) giving various particulars of each of the photographed stones (figs. 1–6)—namely, the dimensions, cubic contents, and estimated weight of each stone when placed in the weir, and the cubic contents and weight of each stone when removed from the weir, together with the percentage of loss during the period of 43 years, and the average annual loss during that time.

In order to estimate the weight of each stone when placed in the weir, a piece of one of the stones, which was an average sample of the whole—and they were throughout of a uniform character—was cut exactly to a six-inch cube; that is, to one eighth of a cubic foot.

This six-inch cube, after saturation in water for three hours,

* A sample of a portion of one of these stones, accompanying this paper, together with a set of photographs (here reproduced, at the Author's expense, figs. 1–6) of six of the stones themselves, were exhibited when the paper was read. In nearly all the photographs the small pebbles referred to are shown *in situ*, as they were found.

Fig. 1. Stone No. 1.

Fig. 2. Stone No. 2.

Fig. 3. Stone No. 3.

Fig. 4. Stone No. 4.

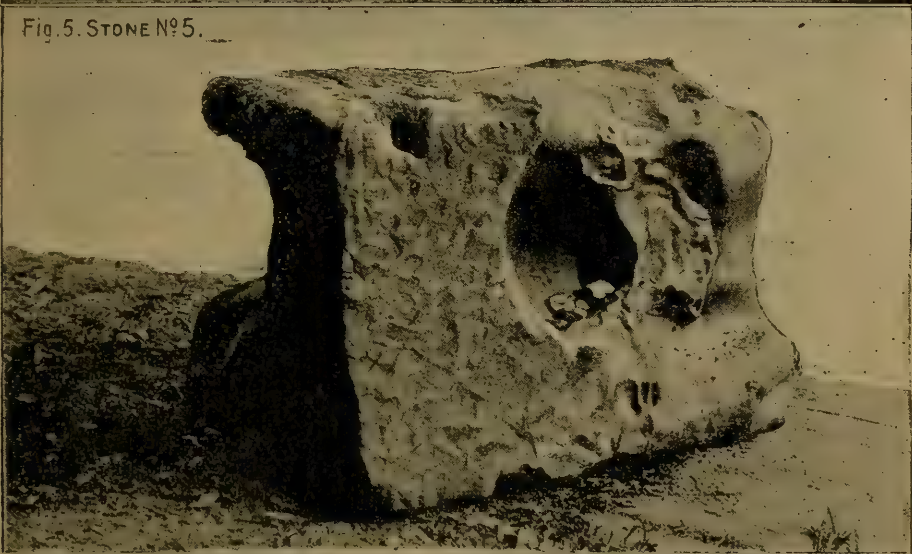


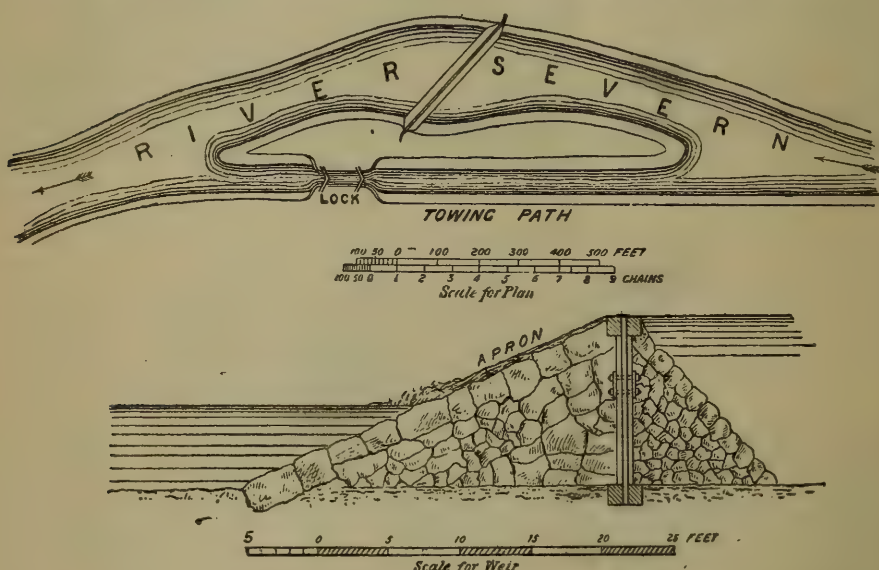
Fig. 5. Stone No. 5.

Fig. 6. Stone No. 6.

weighed 16 lb. 12 oz., thus giving the weight of a cubic foot of saturated stone, as lying in the quarry and in the apron of the weir, as 134 lb.; and the weight of each stone when placed in the weir was estimated on this basis. The stones taken out of the weir were also weighed in a saturated state.

The pebbles were probably rolled by the current in flood-times up the somewhat steep up-stream face of the weir, and deposited, as previously described, in the hollows and joints of the stones forming the flat apron or down-stream side of the weir (see figs. 7 & 8).

Figs. 7 & 8.—*Plan and Section of the Holt Weir on the Severn.*




When the weir was first constructed, the current on the up-stream face was so strong that boulders of considerable size were driven over the crest.

The average quantity of water passing over each square foot of the surface of the stones composing the apron of the weir is estimated at about 2000 gallons a minute; each gallon of water has an average scrubbing-velocity of from 12 to 15 feet per second, and this, acting on the small pebbles, will give some idea of the forces at work for the 43 years during which the stones were in the weir apron.

There are not many instances in which the specific facts relating to the action of water and pebbles upon a certain class of stone can be so accurately ascertained as in the present case; and the writer has therefore ventured to submit a record of them, in the hope that they may be of use to those who may have occasion to investigate the periods of time likely to be occupied in changes resulting from the abrading action of water and pebbles upon the rocky beds of streams and rivers and over waterfalls into ravines.

# APPENDIX.

Particulars of six Water-worn and Pebble-worn Stones taken from the apron of the Severn Commissioners' Weir across the River Severn at Holt Fleet, about eight miles above Worcester.

The stones were placed in the weir during construction in 1844 and were removed in 1887, after having been in the weir apron and subject to the action of the water and the pebbles for 43 years.

The stone is a soft red sandstone, from Holt-Fleet Quarry, which is in the rocks marked F. 5 of the Upper New-Red-Sandstone Formation.

| Number of stone out of set of six. | Dimensions of stone when placed in weir. | | | | | | Cubic contents and estimated weight of each stone at 134 lb. the cube foot when placed in weir. | | | | | Cubic contents and weight of each stone when removed from weir. | | | | | Loss in 43 years. | Loss per annum. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Length. | | Breadth. | | Thickness. | | Contents. | | Weight. | | | Contents. | | Weight. | | | | |
| No. | ft. | ins. | ft. | ins. | ft. | ins. | ft. | ins. | cwt. | qrs. | lb. | ft. | ins. | cwt. | qrs. | lb. | per cent. | per cent. |
| 1. | 6 | 8 | 2 | 0 | 2 | 6 | 33 | 4 | 39 | 3 | 15 | 17 | 6 | 21 | 0 | 0 | 47 | 1·09 |
| 2. | 6 | 0 | 2 | 0 | 2 | 2 | 26 | 0 | 31 | 0 | 12 | 10 | 5 | 12 | 2 | 0 | 60 | 1·40 |
| 3. | 4 | 6 | 1 | 6 | 2 | 6 | 16 | 10½ | 20 | 0 | 21 | 8 | 9 | 10 | 2 | 0 | 48 | 1·12 |
| 4. | 5 | 0 | 2 | 0 | 2 | 8 | 26 | 8 | 31 | 3 | 17 | 13 | 4 | 16 | 0 | 0 | 50 | 1·16 |
| 5. | 4 | 3 | 1 | 8 | 2 | 6 | 17 | 8½ | 21 | 0 | 21 | 11 | 1 | 13 | 1 | 0 | 37 | 0·86 |
| 6. | 5 | 10 | 2 | 0 | 2 | 6 | 29 | 2 | 34 | 3 | 16 | 12 | 1 | 14 | 2 | 0 | 58 | 1·35 |

## Discussion.

Rev. Edwin Hill asked if the Author had any means of telling how far chemical action had operated.

Mr. Hulke wished to know if there was any record of the positions of the six stones given in the table.

Prof. Hughes was desirous of learning whether the stones taken into account were an average sample of the stones.

Mr. Whitaker commented upon the rapid waste.

Mr. Carruthers asked whether the rock was homogeneous.

Rev. H. H. Winwood inquired as to the nature of the pebbles.

The President wished to know whether from the percentages taken some datum could be given for estimating the average loss from the whole surface of the apron.

The Author believed the action was principally abrasive, as there was only a small proportion of lime in the stone which would be the subject of chemical action. The weir was placed diagonally across the river, and the stones referred to, which were average samples, were taken from the apron at the upper end of the diagonal, where the abrasive effect appeared to be greatest. The pebbles were principally of quartzose description. The rock from which the stones were taken was of a homogeneous character. In the case of stone No. 1, supposing the action to have been uniform, the abrasion would represent a loss of nearly one foot three inches from the surface of the stone as originally placed in the apron, and the others in proportion.

[In accordance with a request made by the Council, the Author has added the following notes :—

The stones referred to, which were average samples of the pebble-worn stones which had been removed, were taken from the apron of the weir within a distance of from 40 to 100 feet from the Island end of the weir, where the abrasive effect appeared to be greatest. The stones, however, forming the central portion of the apron, between 100 and 200 feet from the Island end of the weir, were almost similarly abraded and perforated, and would also shortly require to be removed.

Taking the whole surface of the apron, the stones which were not affected by the action of the pebbles were worn down by the action of the water and ice passing over them for an average depth of about 2 inches from their top faces. That might be taken as the average effect of the water and ice alone passing over the weir in the 43 years during which time the apron had been subjected to the action of those forces.—*January* 20, 1891.]

## 7. *On the* Physical Geology *of* Tennessee *and* Adjoining Districts *in the* United States *of* America. By Edward Hull, M.A., LL.D., F.R.S., F.G.S., late Director of the Geological Survey of Ireland. (Read December 10, 1890.)

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3. Direction of Greatest Vertical Movement and Erosion.
4. Formation of the Cumberland Plateau.
II. The Gorge of the Tennessee through the Cumberland Plateau.

### Part I.—§ 1. Introduction.

A recent visit to the Southern States of North America induces me to lay before the Society some observations on the physical aspect of a peculiarly interesting region traversed by the Tennessee River in the State of the same name and the bordering districts. The geological structure of this district has been ably described by Professor James M. Safford, the State Geologist *. The region is now in process of being re-surveyed topographically and geologically under the direction of Major Powell, U.S. Geological Survey, to whom I am much indebted for kind assistance in procuring maps and information †. In the present communication I do not propose to enter at any length into the geological structure of the district here described, but only to single out the most striking features connected with its physical structure, and to endeavour to show how they can be accounted for upon those principles of interpretation which, after many years of discussion and research, are generally adopted amongst geologists. Amongst others we shall have to explain the formation of table-lands, and of the erosion of the gorge by which a great river, the Tennessee, traverses a mountain-plateau in pursuing its way towards the ocean, instead of taking a much more direct course.

* 'Report on the Geology of Tennessee' (1869).

† The sheets, prepared in the Geological Survey Office, are on a scale of $\frac{1}{125,000}$, and are contoured at intervals of 100 feet vertical. A very fine mineralogical map of Tennessee, on a large scale, constructed by Major Kelly, is placed in the Town Hall of Chattanooga.

## § 2. Physical Features.

1. *The Valley of East Tennessee.*—The physical features of East Tennessee are, when viewed on a large scale, extremely simple, and are a faithful index to the geological structure. Along its eastern margin, where Tennessee joins North Carolina, the State follows the crest of the Unaka Range, which may be regarded as one of the parallel ridges of the Alleghanies, and is nearly continuous with the Blue Ridge of Virginia. This ridge is composed chiefly of granite, gneiss, and crystalline schists, presumably of Archæan age, and forming a prolongation of Professor J. D. Dana's "Archæan Protaxis." It attains an elevation of 6760 feet in Black Mountain in North Carolina *, and ranges in a general southwesterly direction. From its base stretches the great plain known as "the Valley of East Tennessee," which extends south-west into Georgia and Alabama, and in an opposite direction is continued into the Valley of Virginia or Shenandoah. This rich and fertile plain has an average breadth of about forty miles, and along its course winds the Tennessee River, a noble stream of about 450 yards in average width. The plain itself is closely furrowed by parallel valleys and ridges, all trending in north-east and south-west directions, parallel to the strike of the beds. The ridges and furrows are in fact the outcrops of the harder and softer strata. The whole valley is underlain by Cambrian and Silurian formations, often highly inclined or thrown into numerous flexures. This series is surmounted by the Devonian beds, here very thin, and consisting chiefly of black shale, which lie close to the base of the northern margin formed by the Cumberland Table-land, which I now proceed to describe.

2. *Cumberland Plateau; Walden's Ridge.*—The north-western margin of the Valley of East Tennessee is formed by the escarpment of the Cumberland Plateau, which rises abruptly above the plain to a height of 1300 to 1600 feet, or 2000 to 2200 feet above the ocean. The crest of the escarpment, formed of massive grit and conglomerate of Carboniferous age, breaks off into mural precipices, often perfectly vertical. As the Tennessee River hugs the base of this escarpment for many miles, the full height of the cliff is thus obtained at one sweep; and as the slopes as well as the summit of the ridge are covered with primæval forest, except where the naked cliff offers no footing for vegetation, the view of this grand escarpment is as striking as it is beautiful.

The escarpment above described forms the south-eastern margin of the Cumberland Table-land, the surface of which is slightly undulating, formed of Carboniferous beds, and which, below Chattanooga, immediately on the west, is traversed by the Tennessee River through a deep and winding gorge about twenty miles in length, where the States of Georgia and Alabama on the south join

* The granitoid rocks of North Carolina are remarkable for the number, beauty, and size of the minerals they have yielded; specimens are exhibited in the museum of the Smithsonian Institution, Washington.

on to that of Tennessee on the north (see Map, fig. 1, facing p. 74). We shall have to discuss the mode of formation of this remarkable gorge later on. The Cumberland Plateau has a breadth of about forty miles north of Chattanooga (lat. 35° 15′ N.), and it breaks off along the north-western margin in a precipitous and lofty escarpment, as along the valley of East Tennessee, but much indented by valleys and coves; while the south-eastern escarpment is seldom broken, but sweeps along the banks of the river in a nearly direct or gracefully-curving line, the indentations of the streams being hardly noticeable *.

The Cumberland Table-land is the southerly prolongation of the Appalachian Mountains; and, though deeply indented by the Cumberland River and its branches in the North-west, is nowhere absolutely cut through by these streams; so that it is only in the gorge of the Tennessee, close to Chattanooga, that the complete intersection of the range is effected. To the south of this gorge the table-land continues into Northern Alabama, till the Carboniferous strata sink down and disappear beneath those of Cretaceous and Tertiary age which border the shores of the Gulf of Mexico. Several terraced and nearly isolated hills, portions of a once continuous plateau, occur along the Tennessee near Chattanooga, of which "Lookout Point," rising abruptly from the river-bank to a height of 2126 feet above the sea. or 1450 feet above the stream, is the most conspicuous example (see Map, fig. 1).

The average elevation of the Cumberland Plateau may be taken at 2000 feet above the surface of the ocean, and 1350 feet above the Tennessee River at Chattanooga; but towards Pennsylvania on the north, at Cross Mountain, it rises to about 2800 feet †, where its structure becomes more complicated. Confining our attention, however, to the region of Tennessee and the borders of Kentucky, we observe that this table-land has the character of a well-defined plateau, formed of massive grit and conglomerate, or other strata, of Upper-Carboniferous age, and intersected by deep ravines, which open out to the south and west, and form the channels of streams draining into the Tennessee, the Cumberland, and the Ohio. (See Sections, figs. 2 and 3.)

Over its whole surface and its flanks this table-land is enveloped in almost continuous virgin forest, consisting of trees of great variety and often of noble stature, with an undergrowth of smaller plants. Nearly fifty varieties of forest-trees may here be counted, including, amongst others, cedars, pines, maples, chestnuts, satin-wood, poplars, and oak of several varieties. These forests give cover to many wild animals, including pumas, bears, deer, hogs, and smaller game. Rattlesnakes and other venomous reptiles lie concealed under the fallen logs, and at night the groves and low-lying woods at the foot of the plateau are lighted up by myriads of fire-flies, while the air is resonant with the croaking of the

* According to Professor Safford.

† In Walden's Ridge, east of the Sequachee Valley, there are tracts reaching the 2300 or 2400 feet level.

tree-frogs. From the crest of the escarpment at various points beautiful and extensive prospects may be obtained of this region of wooded plateaux and wide valleys, where the white man has as yet done little to alter the natural landscape, or to diminish the extent of the primæval forest *.

3. *The Sequachee Valley.*—The table-land thus described is intersected longitudinally by a remarkable valley, that of the Sequachee River, for a distance of sixty miles, in a nearly straight line north-eastward from the banks of the Tennessee near Jasper, with an average breadth of four miles. The narrow plateau thus formed between the valley of East Tennessee and the Sequachee is known as "Walden's Ridge" (see Map, fig. 1). The direction of the Sequachee Valley is therefore parallel to that of the eastern boundary-scarp of the table-land itself, where it overlooks the Valley of East Tennessee. On either side it is bounded by steep and densely-wooded slopes, generally crowned by cliffs of grit or conglomerate; and at its upper end the Sequachee River has its origin in copious springs issuing forth at the foot of the sandstone cliffs.

I was unable to visit the source of this stream, but, from the accounts I had from observers in the district, it must be most remarkable. From the foot of the cliff the waters flow down the steep slopes into a natural caldron, formed in the soft shales and grits overlying the Carboniferous Limestone. The latter here forms a barrier, holding back the waters which have hollowed out a tunnel through the rock, and on issuing forth they descend into the valley in a series of cascades.

The flanks of the Sequachee Valley are composed of Carboniferous grits and shales resting on limestone, from below which the Devonian and Silurian strata emerge with a dip in the direction of the sides of the valley (see figs. 2 and 3). The valley is therefore clearly in the line of an anticlinal axis; and to this it probably owes its origin, though it is possible that there may be a fault here running in a parallel direction, along which river-erosion has acted through a lengthened period. It is a striking example of valleys of this kind. The Little Sequachee, a smaller valley further to the west, is probably due to a similar anticlinal flexure.

4. *Rocks of the Cumberland Table-land.*—The geological structure of the Cumberland Table-land is extremely simple. The strata of which it is formed consist of grits (sometimes pebbly), sandstones, and shale, with beds of coal, all of Carboniferous age, resting on Mountain-Limestone, which crops out in two beds, separated by soft red sandstone, all along the base of the escarpment; the two series constitute in part the "Carboniferous" and "Sub-Carboniferous" groups of American geologists (see figs. 2 and 3).

The Carboniferous series is succeeded, in descending order, by dark Devonian shales, which, owing to their friable nature, have

* This region was the abode of Cherokee Indians, who some years ago were transplanted to the Indian Reserves in the Western States. Shell-mound Station is the site of the terrible slaughter of this tribe by its white and more civilized brethren in 1816, under Major Bond.

doubtless facilitated the work of erosion; and these again by the members of the Upper and Lower Silurian groups, occupying the plains and the central portions of the valleys. The Silurian strata, which are thrown into numerous flexures along the valley of East Tennessee, ultimately give place to others of Cambrian age as we approach the Archæan Protaxis of the Unaka range, forming the south-eastern margin of the plain.

## Part II.—Development of the chief Physical Features.

### 1. *The Cumberland Plateau.*

The physical features, the origin of which I here propose to discuss, are (1) the Cumberland Plateau, and (2) the Gorge of the Tennessee River where it traverses this plateau below Chattanooga. The discussion of the origin of these two leading physical features necessarily involves some reference to the mode of formation of the adjoining areas, that of the Valley of Eastern Tennessee on the east, and that of the Silurian plain of the Cumberland River, or of Nashville, on the west. An inspection of the longer diagrammatic section, from the Archæan Protaxis of the Unaka Range to the plain of the Cumberland River at Nashville, shows in order of succession from east to west—(1) the Unaka Range; (2) the Valley of East Tennessee; (3) the Cumberland Plateau; (4) the Silurian dome or uprise of Nashville; together with the generalized stratification of this tract. (See Sections, figs. 2 and 3.)

1. *The Stratification.*—In dealing with this subject I have to observe that from the base of the Cambrian beds, where they rest discordantly upon those of the Archæan Protaxis, the whole series of Lower- and Upper-Palæozoic formations succeed each other in *apparently* conformable sequence, except at the junction of the Lower- and Upper-Silurian series, where a probable discordance occurs *. Throughout the prolonged period during which these formations were being deposited, there was continuous subsidence, with occasional pauses, over the region lying to the west of the Archæan Continental area, and successive formations of marine strata were laid down in vast sheets over the bed of the ocean, never probably very deep. In later Carboniferous times the marine deposits gave place to those of lacustrine or estuarine origin, but still without any apparent discordance in the stratification; so that the Upper and Lower Carboniferous beds are apparently conformable to each other, and these again to the Devonian and Upper Silurian †.

* According to Professor J. D. Dana, this discordance is very marked in the New-England States, where the Lower-Silurian beds have been metamorphosed and elevated with the Archæan rocks. In their southern prolongation this is not so evident, but highly probable. See J. D. Dana, "Areas of Continental Progress," Bull. Geol. Soc. America, vol. i. 1889.

† I use the expression "apparently conformable," because, though there may be discordances of stratification, they are so small as not to have been recognized.

2. *Epoch of Greatest Terrestrial Movements.*—The prolonged period of subsidence and deposition above described at length gave place to an epoch of elevation and contraction of the crust, acting with greatest effect and intensity along the line of the Alleghanies, and parallel with the Atlantic sea-board, where the Palæozoic strata are folded, flexured, and even reversed, along parallel axes, as so admirably illustrated by the late Professor H. P. Rogers *. The foldings of the strata, it is well known, generally subside in a westerly direction towards the Valley of the Ohio, and ultimately pass into widely extended dome-shaped centres of elevation with intervening areas of depression. Amongst the former are the "Cincinnati uplift" and the anticline of the Nashville Silurians; amongst the latter is the region of the Cumberland Plateau, which lies along the centre of a broad syncline.

3. *Direction of Greatest Vertical Movement and Erosion.*—From what has been said, it clearly follows that the greatest amount of vertical movement, consequent on powerful lateral thrust, was along the Archæan Protaxis of the Alleghanies. All along this line the Palæozoic strata were elevated thousands of feet above the ocean, and subjected in consequence to great denudation; this process was doubtless facilitated by the flexures and fissures accompanying the movement. Away from this axis of disturbance, the strata (as has been already observed) were but slightly moved, with the result that they remained under water and undenuded, or but slightly emergent, long after those on the border of the Archæan Protaxis were being subjected to extensive erosion.

Under these conditions denudation proceeded more rapidly along the tract bordering the Protaxis, and especially along the arches or anticlinal flexures. The synclines, or trough-shaped areas, were protected from erosion to a greater or less degree. In the region with which we are specially concerned, the line of the Unaka Range and Blue Mountains, which was perhaps never altogether submerged, was upraised gradually into high land. The Cambrian and Silurian strata were subjected to erosion; and streams carrying the materials flowed down the flanks of the emergent land into the sea or estuary to the westward. This process was going on all through the Mesozoic period. As time went on, these western tracts, wherever in the line of anticlines, were themselves elevated and eroded, and ultimately the synclines themselves; but the necessary result of this unequal process of erosion would be to leave the synclinal tracts relatively higher than the anticlines. At a later epoch the Cumberland Plateau began to be formed by the cutting back of the strata in the direction of their dip; the massive Carboniferous grits, resting on softer strata largely formed of shales, presenting the necessary conditions for the development of a crested ridge.

4. *Formation of the Cumberland Plateau.*—We are now in a position to understand the primary conditions under which this plateau was developed. First there are the required stratigraphical

* 'Geology of Pennsylvania.'

[To face p. 74.

g. 1.—*Map of a part o*ƒ*ooga.*

[To face p. 74.

# MAP AND SECTIONS

TO ILLUSTRATE

DR. E. HULL'S PAPER ON THE PHYSICAL GEOLOGY

OF

THE TENNESSEE AND PARTS OF ADJOINING DISTRICTS

IN THE

UNITED STATES OF AMERICA.

Fig. 1.—*Map of a part of the State of Tennessee, showing the Gorge of the Tennessee River near Chattanooga.*

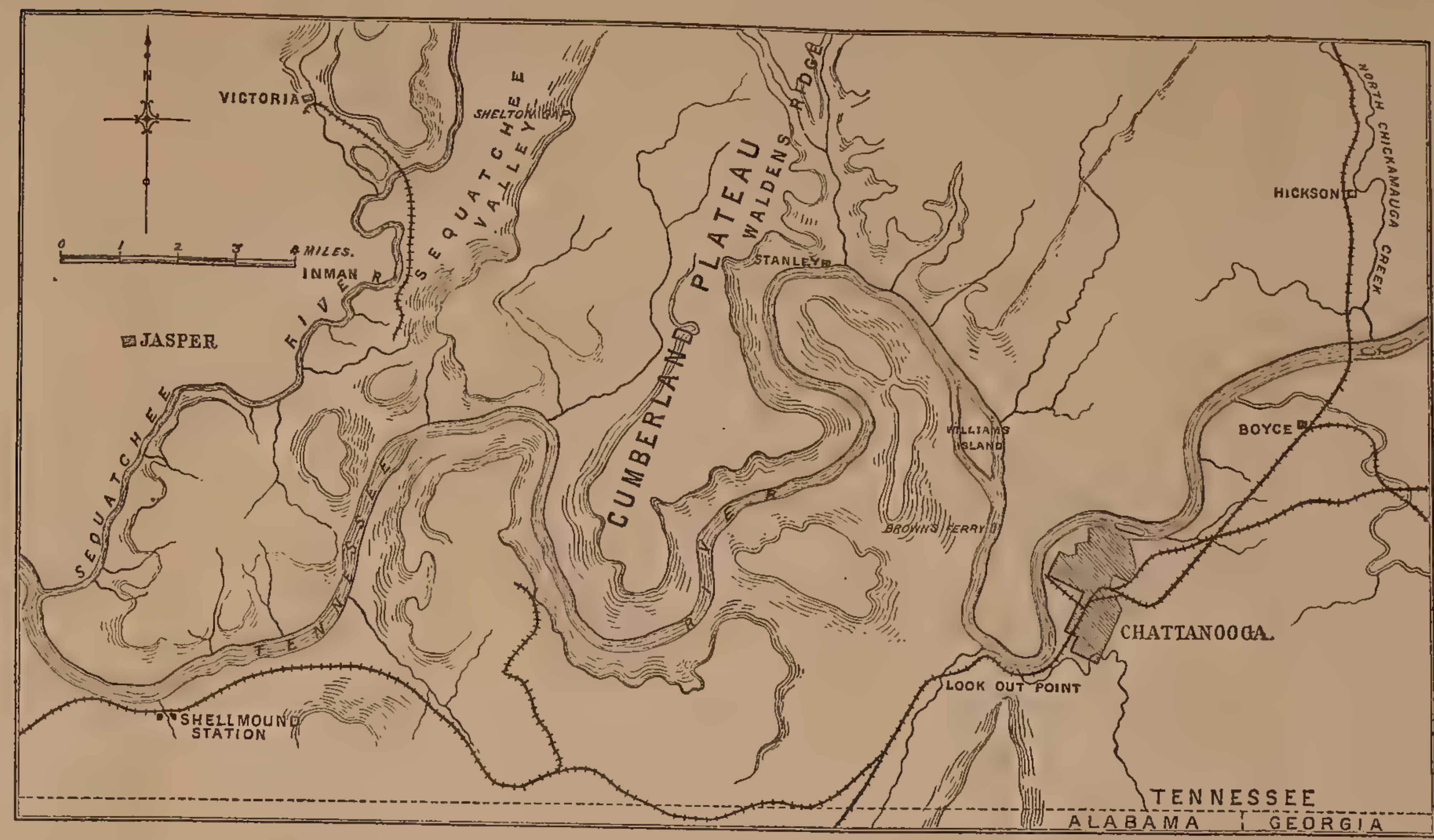
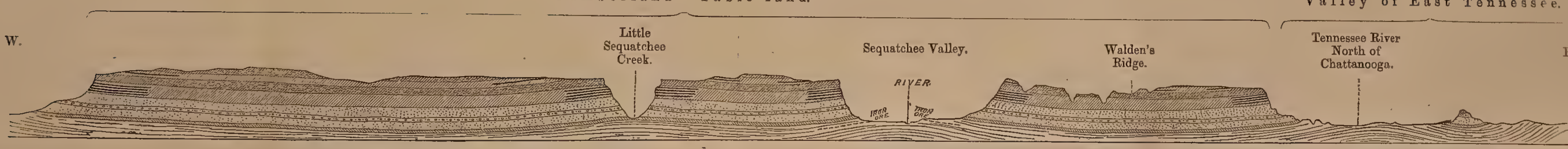



Fig. 2.—*Section across the Cumberland Plateau to the East Tennessee Valley.*




*Explanation of* Fig. 2.

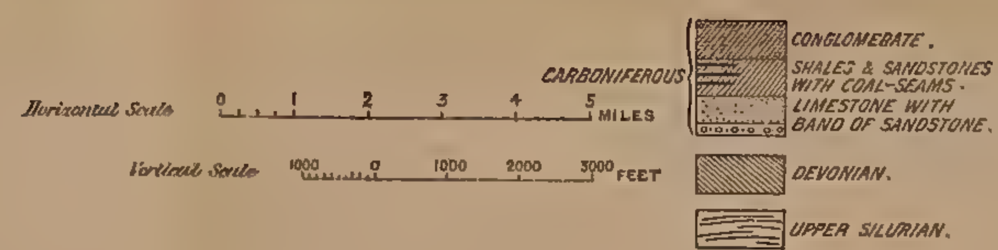
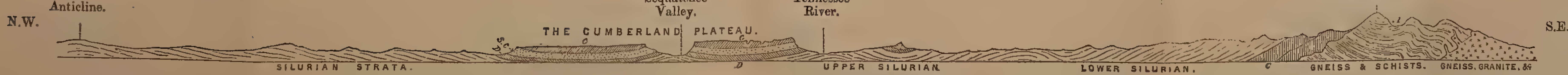



Fig. 3.—*Generalized Section across the State of Tennessee.* (Length about 200 miles.)




*Explanation of* Fig. 3.

conditions, namely hard grits or sandstones resting on soft strata, and these occupying the line of a low synclinal axis, ranging in a N.E. and S.W. direction. The strata in this position being the latest which were upraised, were preserved almost intact; while those continuous with them, and forming the flanks of the parallel anticline, were denuded away. The simple conditions here stated are somewhat modified by the two secondary anticlines along the Sequachee Valleys; but these do not affect the general position, and are themselves examples of lesser valleys eroded along anticlinal axes.

It should also be observed that the Tennessee River, continued into the Clinch River, keeps close to the base of the escarpment of the Cumberland Plateau (Walden's Ridge); and we may suppose that, as this escarpment was cut back in the direction of the dip, the river itself gradually moved westward, or in the same direction*. Thus the Cumberland Plateau was developed by the erosion of the Valley of East Tennessee on the one hand, and by a somewhat similar series of physical operations along the Valley of the Cumberland River on the other or western side.

### II. *The Gorge of the Tennessee through the Cumberland Plateau.*

The course of this stream, the fourth in size in the United States, is most remarkable, and requires to be explained on geological principles. Descending (under the name of the Little Tennessee) from the Blue Ridge (or Archæan Protaxis), it crosses the Unaka ridge in a north-westerly direction to Kingston; here it joins the Clinch River, coming down the Shenandoah Valley in a south-westerly direction; and this course it retains, flowing along the foot of the Cumberland Plateau to Chattanooga, when it changes its course, and traverses the plateau by the gorge already described. Ultimately the Tennessee, instead of continuing its course in a southerly direction into the Gulf of Mexico, makes a great sweep to the northward and joins the Ohio at a distance of about forty miles above the junction of that river with the Mississippi, thus adding to its course a length of about 800 miles!

The east and west saddle or water-parting, from which the streams drain into the Tennessee on the one side and into the Gulf of Mexico on the other, descends to a level of about 920 feet above the waters of the Gulf a few miles south of Chattanooga. The level of the saddle is only 270–280 feet above the river at Chattanooga; so that (to put the case in popular language) we may say that the Tennessee, rather than take a direct course towards the Gulf by crossing a saddle which is only 270–280 feet above its bed, has preferred a channel through a table-land rising 1400–1500 feet above its bed—a course

* If we regard the direction, the Tennessee River is the real continuation of the Clinch downwards, and the Little Tennessee is a lateral tributary. The Tennessee at a former period probably ran in a channel further east and at a higher level.

which shows that the original relative levels of the saddle and the plateau have been absolutely reversed.

In brief, therefore, we infer that when the river began to erode its channel in the region of the Cumberland Plateau, this tract was relatively lower than that to the south of its present course. By the process of denudation these relations have been reversed; but the river, having once begun to wear down its channel, continued to deepen it as the land rose; so that, having once selected its course, it never afterwards left it.

If it be permitted to compare small things with great, we may say that the process of valley-erosion as applicable to the Tennessee is somewhat analogous to that which took place in the South-east of England during later Tertiary times, in consequence of which streams, such as the Medway and the Ouse, pass into the sea by channels traversing the escarpments of the Chalk and Lower Greensand. The high grounds forming the sources of these streams in the centre of the Wealden area represent the ridge of the Unaka and Blue Mountains; the plain of the Weald Clay represents the Valley of East Tennessee, and the escarpments of the Greensand and Chalk the Cumberland Plateau. How these channels were formed, together with the adjoining escarpments, has been ably explained by Messrs. Foster and Topley in their joint paper on the "Denudation of the Weald" *, and further illustrated by Sir Andrew Ramsay †. The principles of interpretation which have been adopted in the one case are applicable in the other, though on a larger scale, and need not be repeated ‡.

The effects of denudation here described were doubtless accelerated during the "Pluvial" or "Champlain" Period, corresponding to the later stages of the Glacial Period. This region was, it is true, far to the south of the limits of the great ice-sheet of North America, as shown by Mr. T. C. Chamberlain §; but the evidences of extraordinarily copious rainfall and of the former erosive and transporting action of the rivers over the regions lying along the margin of the great ice-sheet are abundantly evident, and are fully recognized by American geologists. Along the eastern side of the Alleghanies the representative of this epoch is the "Columbia Formation" described by Mr. W. J. M'Gee ‖; and to a similar stage is probably referable the remarkable deposit of red loam by which the surface of the country in the valleys of the Tennessee and Sequachee is overspread to a depth of many feet or even yards. The effects of extensive aqueous erosion, and the consequent deposition of sediment in the valleys beyond the reach of existing streams, are everywhere manifest in this part of America.

* Quart. Journ. Geol. Soc. vol. xxi.

† 'Phys. Geol. & Geogr. of Great Britain.'

‡ It is right to observe that Professor Safford and Mr. J. P. Leslie account for the preservation of the Cumberland Plateau by faulting, which has relatively lowered the Carboniferous strata; but the well-defined escarpment with which the strata crop out along the Valley of East Tennessee near Chattanooga seems to me to show that such a cause is insufficient.

§ 'Seventh Annual Report U.S. Geol. Survey,' p. 155.

‖ *Ibid.*, "Taxonomy of the 'Columbia Formation,'" p. 611, &c.

## Discussion.

Mr. Topley thought the parallel drawn by the Author with the Wealden area was in part justified, but there were differences connected with minor points. The structure had been worked out in detail for the Wealden area, but a similar state of things existed in other parts of England. The watershed between the East Tennessee valley and the Gulf of Mexico must have been greatly lowered.

Prof. Hughes asked if the gravels of the high terraces were composed of Silurian or Carboniferous detritus, as he wished to know whether the Carboniferous beds of the plateau had been continued over the East Tennessee valley at the time of the formation of the gorge. The northerly direction of the river after leaving the plateau suggested change of level.

Mr. Wills compared the area described with the gorge of the Avon at Bristol.

Dr. Hyland had not been led to any definite conclusion during his short stay in the region.

The President found difficulties here, as elsewhere, in realizing the form of the ground when the rivers began to flow, and in discovering whether there were subterranean movements which affected the denudation. He felt that the explanation of the topography might not be so simple as Prof. Hull made out, and would like to have more details as to the structure of the ground.

The Author, in reply, concurred with the remarks of the President as to the complex character of the subject. He thought the fault drawn by Prof. Safford on the east side of the plateau had little to do with the formation of the escarpment. He had no evidence to adduce in answer to Prof. Hughes's question. There was no more reason why the river should have flowed south on the west than on the east of the plateau.

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## 8. *On the* North-west Region *of* Charnwood Forest, *with other Notes.* By the Rev. Edwin Hill *, M.A., F.G.S., and Professor T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S. (Read January 7, 1891.)

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  4. Field Relations of the Peldar and Sharpley Rocks.
  5. Bardon Quarry.
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  6. Stable Quarry, Bradgate Park.
  7. The Igneous Junctions.
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  9. The Blackbrook Group.
  10. Fragments and Pebbles.
  11. Glacial Phenomena.
  12. Age of the Clastic Charnwood Rocks.
  13. Age of the Igneous Rocks.
  14. Corrigenda.

### I. Introduction.

It is now more than ten years since the last of our papers on the pre-Carboniferous rocks of Charnwood Forest was laid before this Society †. At that time, as we stated, we had no expectation of writing further upon the district. But since then, though little has been changed in the Forest, beyond the enlargement of some quarries, the general progress of knowledge has affected our interpretation of some of the facts which we had ascertained, and much has been learnt in regard to the whole subject of metamorphism, especially as to the effects of pressure, due to movements of the earth's crust, in modifying rock-structures and initiating, if not producing, mineral changes. We have, we hope, more knowledge and a wider experience, so that our interpretation might be altered, though the facts might be unchanged ‡.

Now there was one district in the Forest, that of Peldar Tor,

* Mr. Hill desires to state that throughout this paper all references to microscopic evidence are due to Professor Bonney. He himself has taken part only in the field work.

† Quart. Journ. Geol. Soc. vol. xxxvi. (1880) p. 337.

‡ Not much has been published since the date of our last paper. There is a good account of a visit of the Geologists' Association published in their 'Proceedings,' vol. x. (1888) p. 472, by Mr. J. D. Paul, to which is appended a useful note on the microscopic structure of some of the rocks, by Major-Gen. McMahon, who expresses the opinion that the rocks of Sharpley and Peldar Tor are lavas. Mr. W. J. Harrison refers, in some papers on the pre-Carboniferous floor of the Midlands, to the rock of Charnwood ('Midland Naturalist,' vol. viii.), and describes the syenites of S. Leicestershire (*ibid.* vol. vii.), but adds nothing material to our notice, to which he does not refer.

with Sharpley and Bardon Hill, in regard to which, as stated at the time *, we had found great difficulty in deciding whether the rocks had been originally ashes or lavas; that is to say, whether the fragmental structure, which could be dimly traced, had been present from the very first, or had been superinduced. We discussed the question at length, giving, to our best ability, the arguments on each side, and coming to the conclusion that the rocks of Peldar Tor, of Sharpley, and of Bardon Hill were all of pyroclastic origin. Still, as expressed at the time, this view was not without considerable difficulties, especially in regard to the first and second, and during the following three or four years new factors were introduced into the problem, of which account had to be taken.

The researches of Lehman, Heim, and others, coupled with our own work in other fields, indicated that earth-movements were far more effective than had hitherto been supposed in producing brecciation and clastic structures in large masses of rock, which originally had been homogeneous or crystalline. Again, increased experience showed us that from flow-brecciation and other causes a fragmental structure was of commoner occurrence in a true lava than we had expected, and that the general uniformity of character which was presented by the rocks of Peldar and Sharpley over such large areas was very difficult to parallel in the case of tuffs. One thing, however, more than any other made a reconsideration of the question absolutely necessary: we referred in our discussion to the porphyroids of the Ardennes as presenting very close resemblances to the Peldar and Sharpley rocks, especially to the latter. These had been examined by eminent geologists, who had discussed their origin, and denied it to be igneous †. In 1882, however, one of us was able to visit the Ardennes, and came without any hesitation to the conclusion that these porphyroids were simply igneous rocks modified by subsequent pressure ‡. This of course struck away one of our chief supports, and led us to examine the Charnwood district anew. We were the more hopeful of some result, because the publication of the six-inch map made it possible to record our observations with a detail which was impossible on the ordinary one-inch map, and thus to obtain a clearer idea of the form of the areas occupied by these rocks, and of their relation to others in the neighbourhood. Accordingly, during visits in the spring of 1887, 1889, and 1890, we carefully re-examined not only all the north-western part of the Forest, but also a few other localities about which we felt some difficulty or were hopeful of additional evidence.

## II. The North-west Region and Bardon Hill.

1. *General Description of the North-west Region.*—This district is entirely included within lines drawn through Abbot's Oak (or Greenhill) and the Whitwick-village Quarry (Pinfold Quarry) on

* *Op. cit.* pp. 341–348.

† 'Les Roches Plutoniennes de la Belgique,' &c. p. 246.

‡ Bonney, Proc. Geol. Assoc. vol. ix. (1885) p. 247.

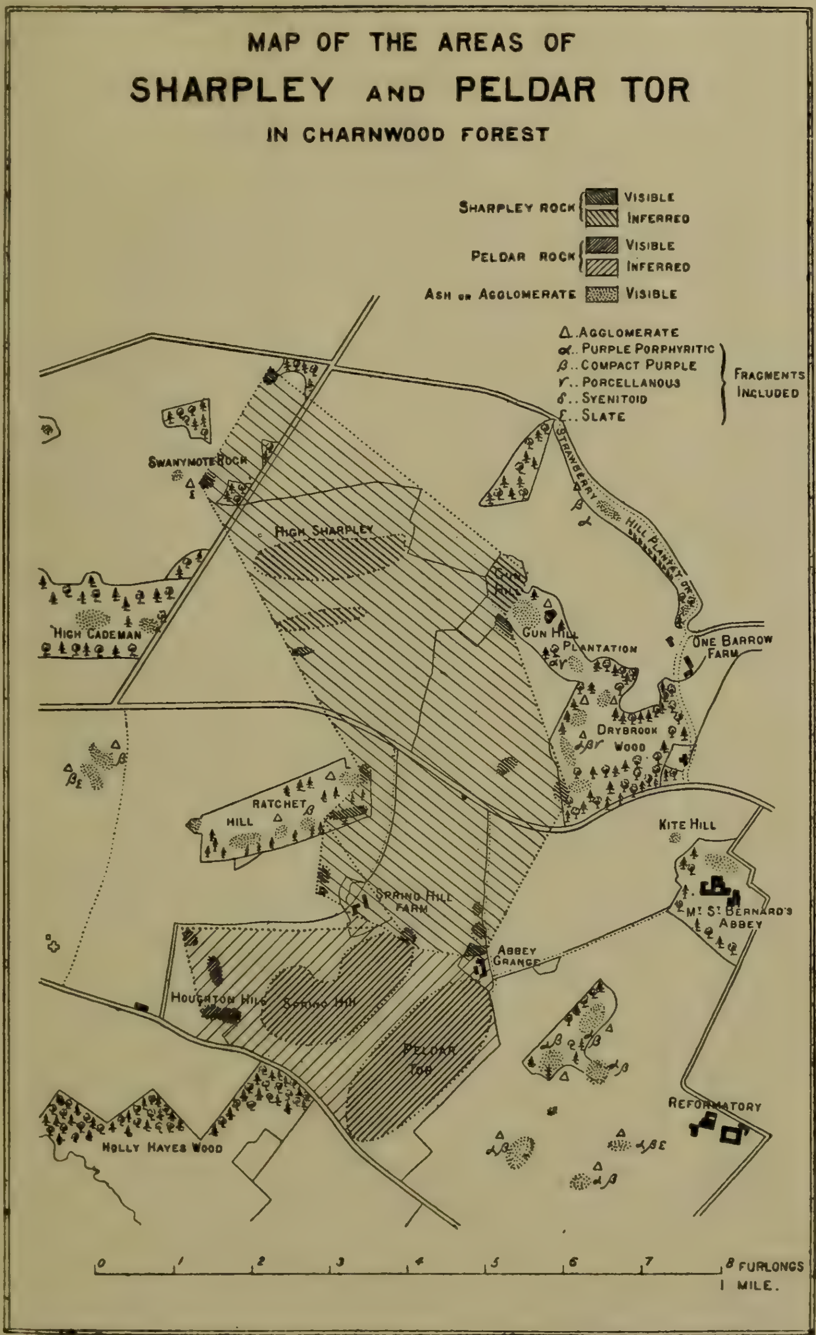
the one side, through the plantations of Strawberry Hill and Cat Hill on the other, and from Abbot's Oak, skirting Timberwood Hill, across these two. These boundaries are probably natural ones, for they follow the features of the ground, and do not leave any outcrops outside, though many come close to or are upon them.

The first line is parallel to the well-marked horizon of the Blackbrook Group, and the second (about a mile from the first) only makes an angle of 7° with that horizon. The third, if produced, also skirts the slopes of Bardon Hill and suggests a fault. The boundary of visible rock in the remaining direction (N.W.) is irregular. The rocks within these limits have few representatives in the rest of the Forest. The outcrops from the S.E. boundary up to Peldar Tor and Sharpley are, in general, confused heaps of agglomerate, and ashes without large fragments are rarely seen. Then come the areas occupied by the porphyroids of Peldar Tor and Sharpley which are in contact along a very short line (from Abbey Grange to Spring Hill Farm, about a quarter of a mile). The remainder of the region also contains agglomerates and ashes, the latter, without conspicuous fragments, being more frequent than in the southern part; yet even here the majority of outcrops are agglomerates. Even the very flinty slate at the Car-Hill Quarry, Whitwick, and at that near the Forest-Rock Hotel do not indicate thick masses, and are seen to pass into beds of ashy materials.

2. *The Porphyroid of Peldar Tor.*—We have little to add to or correct in our published description of the general macroscopic characters of this rock. The dull green colour of the matrix, the rough external surface, the rugged and almost lumpy weathering are features markedly characteristic. We have observed, however, that some of the outcrops on the western margin of the mass approach the Sharpley type in that they display a smoother surface and a tendency to bleach in weathering. Included fragments are not numerous, and are generally small, though occasionally a fragment several inches in diameter may be found *. Some resemble the porphyritic felstone which is common in the neighbouring volcanic breccias; others (the more numerous) are a rather fine-grained reddish-grey rock. The Peldar porphyroid, here and there,

* The largest which we observed was 18″ in diameter—an exceptional size. This specimen under the microscope exhibits a groundmass consisting of numerous small felspar crystals—often about ·02″ long—some with Carlsbad twinning and resembling orthoclase, some plagioclase. The intervals are blackened with opacite or occupied by viridite. We find also grains of epidote and of iron oxide (? ilmenite more or less altered). In this groundmass are one or two small grains of quartz and several larger crystals of felspar, some showing plagioclastic twinning. All exhibit a rather rounded central part speckled with opacite, surrounded by a clearer margin, which has a more rectilinear boundary. A slide from a compact-looking fragment, collected from the S. side, much resembles in general character the rock of the "purple porphyritic" fragments at Ratchet Hill, &c., though the quartzes and felspars are smaller, and its groundmass puts on occasionally the slightly "granular" aspect characteristic of the ordinary Peldar rock. Now and then these "granules" give indications of spherulitic structure. There is a nest of small felspar crystals and epidote (?), an inclusion from a yet older rock.

[To face p. 80.


MAP OF THE AREAS OF
SHARPLEY AND PELDAR TOR
IN CHARNWOOD FOREST
Sharpley Rock
Visible
Inferred
Peldar Rock
Visible
Inferred
Ash or Agglomerate
Visible
Δ..Agglomerate
α..Purple Porphyritic
β..Compact Purple
γ..Porcellanous
δ..Syenitoid
ε..Slate
Fragments Included
Swannymote Rock
High Sharpley
Strawberry Hill Plantn
Gun Hill
Gun Hill Plantation
One Barrow Farm
High Cademan
Drybrook Wood
Ratchet Hill
Kite Hill
Spring Hill Farm
Mt St. Bernard's Abbey
Abbey Grange
Houghton Hill
Spring Hill
Peldar Tor
Reformatory
Holly Hayes Wood
0
1
2
3
4
5
6
7
8 Furlongs
1 Mile.

## EXPLANATION OF THE MAP.

This Map, traced from the Ordnance Survey on the six-inch scale, shows the areas in which the porphyroids of Sharpley and of Peldar Tor are exposed, and the regions beneath which they probably occur. The latter are obtained approximately by connecting together the outermost outcrops of each type of rock with straight lines, so as to define an area within which no other rock is visible. The Map also marks the outcrops of other rocks surrounding the above-named areas, and indicates their nature in each case. No attempt has been made to give an accurate representation of the outlines of the visible rock-masses. The place has been determined by the indications on the Map, and the outline sketched in from memory; moreover, in some cases a number of separated outcrops, which are in proximity one to another, are represented as if they formed, as no doubt they do, a continuous mass.

has an aspect which suggests a "fragmental" origin, and its mode of weathering certainly more resembles that of an indurated homogeneous volcanic ash than of a lava. A rough cleavage can generally be discovered on closer examination. Its strike is approximately W.S.W.–E.N.E. (sometimes more nearly approaching W.–E.), with a very high dip on the northern side.

Though much attention has been paid to the microscopic structure of the rock, we have little to add to our former remarks. The larger felspars are sometimes to a great extent replaced by epidote, which, by the mode of its occurrence, appears to have formed direct from the other mineral, almost as a paramorph, instead of resulting from a general exchange of constituents with the neighbouring minerals. This change would most readily occur in the case of an andesine- or labradorite-felspar, provided some of the soda and of the silica were removed by solution. But an addition of some iron would seem requisite. This, however, might have been obtained from enclosures of iron oxide or ferriferous glass. Epidote and viridite are sometimes associated: the latter also occurs alone, and varies from an isotropic mass to an aggregate of flaky minerals, which have only a feeble action on polarized light; probably these belong to the chlorite group, although in some cases they may be nearer to serpentine. These may indicate the former presence of a member of the pyroxenic group, but neither the external form nor the structure of the grain helps us to a conclusion. We think it probable that the grains composed of viridite and abundant opacite, for the origin of which garnet or even olivine was vaguely suggested in our former papers, are an iron oxide, in some cases at least ilmenite, where the grain has been partly converted into a mineral allied to chloropal. The quartzes are cracked, but, as a rule, do not exhibit strain-shadows. The cracks sometimes are occupied only by viridite or an allied secondary mineral, and appear connected with a linear structure indicative of crushing of the adjacent rock, in which case we refer them to subsequent pressure. But occasionally they are partly occupied by material corresponding with the matrix, and suggest that they are due to strains set up before it solidified. For instance, in one slide, small angular bits of quartz are exceptionally numerous, and occupy positions in relation to an inlet in a large quartz grain (like a wedge cut out of a round cake); and this seems as if they came from the gap. Sometimes the quartzes have a fairly-defined crystalline outline, but generally they are more or less rounded, and occasionally seem to have been invaded by the matrix.

Some difficulties as to the structure of the last have been cleared up by additional study. We called attention formerly to a peculiar spotted character produced by thin lines of a green mineral which seemed to traverse the whole in a kind of network. This, it is now clear, is a secondary product, replacing a black iron oxide, and so it is most likely a variety of chloropal. As the rock cooled, probably the iron, as usual, separated out of the glass, and then a concretionary action was set up in the latter, expelling the opacite,

and causing it to aggregate as a kind of network between their walls. Subsequent change, perhaps devitrification, and certainly the action of water, brought the rock to its present condition.

The rock which we mentioned as occurring on the north side of the Bardon-Hill Pit, and apparently identical with that of Peldar Tor, has been much more fully exposed, owing to the enlargement of the quarry. It is indubitably, macroscopically and microscopically, identical with that of Peldar Tor. It contains rock-fragments, similar to that described above. In one place a slightly more compact variety occurs. The matrix of this does not exhibit the usual spotted structure, but gives a very faint indication of a fluidal structure. This Peldar rock overlies, with a rather irregular base, a porphyroid which bears, as will be shown in our account of the pit, a general resemblance to the rock of Sharpley, and, in this, fragments and possibly lenticular streaks of the characteristic Peldar rock are sometimes abundant.

We have thus been led to abandon our idea that the Peldar porphyroid had a pyroclastic origin, and now regard it as a lava, somewhat modified by various secondary changes. The appended analyses *, kindly made in duplicate for us by Miss E. Aston, B.Sc., in Professor Ramsay's laboratory at University College (London), indicate that, as we had been led by microscopic examination to expect, the rock is rather intermediate in its position; but on the whole it is more nearly allied to the dacites than to the rhyolites. Hence it should be named either an altered dacite or a porphyrite.

3. *The Porphyroid of Sharpley.*—In our last paper we called attention to the very close resemblance which this rock presented to a lava, but, for reasons there given, preferred to regard it as the result of the alteration of a tuff which had a rather uniform character. Further study, however, has increased the difficulties which existed in the latter view, and diminished greatly those in the former.

The fragmental character of the normal rock is due, we now believe, to the pressure which has produced the schistosity, and led to the development of films of sericite. To the same cause the cracking of the quartzes, at any rate in most cases, must be attributed. We are, however, still of opinion that a small mass of pyroclastic rock occurs near the west end of the southern ridge, and a yet smaller one some distance east of it, as already described. These appear to pass imperceptibly into the normal rock, and thus to support our former view; but we can see that this difficulty in finding a division might arise if the lava had originally a rather smooth, slaggy surface, and the ash consisted of fragments and powder of an identical rock. That this was really the case there is, as will presently be shown, good reason to believe. The differences in

| * | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | CaO | MgO | $Na_2O$ | $K_2O$ | Total. |
|---|---|---|---|---|---|---|---|---|---|
| No. I. ...... | 71·44 | 10·54 | 3·81 | 2·23 | 5·33 | 2·95 | 1·93 | 0·84 | 99·07 |
| No. II. ...... | 71·68 | 10·39 | 4·09 | 2·23 | 5·45 | 2·50 | 1·93 | 0·84 | 99·11 |

Only one analysis was made of the amount of $Na_2O$ and $K_2O$; the loss by drying and ignition was not estimated.

microscopic structure between the Sharpley and Peldar rocks are not conspicuous. In the former, the dusty opacite is, as a rule, only very rarely replaced by the green silicate already mentioned, and is less regularly aggregated; so that the rock, under the microscope, has a more streaky or blotchy aspect instead of the peculiar spotted or speckled look of the other. Still this may be seen occasionally.

Our old specimens have been repeatedly studied, and some new ones examined, with the result that we feel more confidence in attributing the occasional indications of a fragmental structure, which the rock exhibits, to mechanical movements subsequent to its consolidation—that is, to the cause which has produced its schistosity; and we find, in its general structure, increased resemblances to a glassy lava, which has been subsequently devitrified. Traces of pyroxenic minerals are rarer in the porphyroid of Sharpley than in that of Peldar Tor. But in some slides, brown, almost opaque, rather roughly shaped belonites, about ·005″ long, are fairly common. These occasionally become almost translucent and colourless, perhaps owing to the conversion into chalybite of the colouring limonite. They are feebly anisotropic, and may possibly indicate the former presence of a pyroxene rich in iron. Larger grains of an iron oxide, somewhat decomposed, occur occasionally, and the granular blackened mineral, described in the Peldar-Tor rock, is here much more rarely seen.

The order of the phenomena in both rocks seems to have been the same, and may be summarized as follows:—

(1). Formation of quartzes, felspars (with a slight tendency to occur in groups of two or three), iron oxides, and other minerals (*e. g.*, pyroxenic).

(2). Partial corrosion of the quartzes and felspars, with occasional fracture of the former (at least).

(3). Consolidation of the matrix, segregation of opacite, formation of minor structures.

(4). Production of a rude cleavage; principal cracking of the larger included minerals.

(5). Devitrification, &c.—Order of (4) and (5) uncertain; the latter doubtless a very prolonged process.

An analysis of the Sharpley rock was made by Mr. Berry in 1882*, and a partial one is given in our last paper †. The large amount of $Na_2O$ compared with $K_2O$ in the former analysis appeared strange, for microscopic examination had indicated that a fair amount of the porphyritic felspar was orthoclase. At our request, Miss Aston kindly undertook to determine the amount of these constituents in another specimen; this gave $Na_2O = 2{\cdot}43$ and $K_2O = 2{\cdot}18$, which we believe better expresses the normal composition. The percentage of $SiO_2$ was high, about 77·8 ‡; Mr. Berry obtaining 67·6, the other observer 68·05. Probably the fragment recently analysed contained

* Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 199.

† *Ibid.* vol. xxxvi. (1880) p. 342.

‡ One analysis gave $SiO_2 = 77{\cdot}70$; another, 77·88.

a greater number than usual of the included quartz-grains. Unless a very large amount of the rock be pounded up, discrepancies of this kind are inevitable. About 70 per cent. of $SiO_2$ would probably be near the general average. Thus the rock represents an ancient dacite rather than a rhyolite, but, as is often the case in the Forest, is somewhat intermediate in character. The Sharpley rock, when fresh, allowing for the presence of the quartzes, might have had a general resemblance to the older andesite of Krakatoa *.

4. *Field Relations of the Peldar and Sharpley Rocks*†.—It is remarkable that the areas occupied by these two porphyroids are so constantly environed by agglomerates. With only one exception ‡, fragments will be found in the outcrops, nearest to any point of their boundaries, and the agglomerates in the spinneys east of the Peldar moorland are among the coarsest in the Forest.

The agreement between two boundaries of this region and the usual directions of strike suggest that they may be in some way connected with surfaces of deposition. The Peldar rock also occupies a position which would agree with its being part of a stratified series, regularly overlying the Sharpley. But this view is negatived by the abrupt termination of the former against the agglomerates and ashes of Ratchet Hill, which are exactly in the usual direction of strike; it is limited as completely in the opposite direction. If we define the two areas of Sharpley and Peldar rocks by straight lines drawn joining their outermost outcrops, we find the Sharpley rock covering a rude parallelogram §, about three times as long as it is broad, while the Peldar occupies a much ruder parallelogram of only one-third the size, touching along a small portion of its longer side the Sharpley area (see Map, facing p. 80). It is scarcely possible to account for the restriction of these rocks to such strictly limited and peculiarly-shaped areas by faulting. But these difficulties disappear if the rocks are regarded as two lava-flows.

A rock which we found in a spinney (rudely trilobate in form) not quite one-third of a mile W.N.W. of Swanymote Rock, between the northern end of Cademan Wood and the road, may be mentioned here. It occurs near the outside of the southern end of the spinney, and can be traced fairly continuously over an area extending about 30 yards in a northerly direction, and perhaps 4 or 5 yards wide. Macroscopically, it is rather intermediate in character between the normal Sharpley and the "purple porphyritic" rock which is common in the agglomerates; that is, it is like the former, but the individual crystals are not quite so large. Under the microscope the felspars are similar, suggesting in their outline fracture or corrosion. They contain sometimes frequent enclosures,

* Report of Krakatoa Committee of the Royal Society, plate iii. fig. 1.

† See Map, facing p. 80.

‡ Drybrook Wood (S. end), where Sharpley rock is seen within a few feet of ashy rocks.

§ It is also noteworthy that, corresponding to an indentation in the Sharpley boundary at Ratchet Hill, there is a similar indentation in the opposite boundary by Gun Hill, as if the parallelogram had been broken across and the parts displaced.

now viridite, but suggestive of having been a glass. The quartzes, though fewer and smaller, are like those of Sharpley and Peldar: there are the occasional small clusters of epidote and the composite grains, darkened with opacite. The slide includes at one edge a small portion of a felted mass of small plagioclastic felspars with a little epidote and black iron oxide, which recalls the structure of the fragments included in the Peldar rock, and the matrix now resembles that of the latter, now that of the Sharpley rock—the two being rather "streaked" together, as if a slight fluidal structure were present. The mode of occurrence and aspect of this rock in the field suggests that it is a dyke, and this view accords fairly with the microscopic structure. If so, it confirms our present interpretation of the typical Sharpley and Peldar rock. It is, we may add, the only case in which field evidence strongly suggested the presence of a dyke in this region, and this is certainly remarkable, seeing that agglomerates and ashes are so abundant.

The outcrop called the Swanymote Rock*, at the north-western extremity of the Sharpley *massif*, presents considerable difficulties. The mass may be roughly divided by a line running from rather N. of N.W. to rather S. of S.E. The portion on the eastern side contains fragments of a dull-purple porpbyritic rock, like that often seen in the neighbouring agglomerates. In that on the western side it is doubtful whether any of these fragments are present, but pieces of slate, sometimes quite 2 feet long, occur, generally green in colour, but in a few instances purple. Once or twice they are distinctly banded, and they have been bent, but the bending was apparently anterior to the production of a cleavage in the matrix, which has hardly produced any effect on them. The matrix of the *massif* is rather irregular in structure—quartzes and felspars abound. The rock sometimes appears identical with the normal porphyroid of Sharpley, but occasionally is more suggestive of a pyroclastic origin. An adjoining knoll, to the W., in parts resembles the purple porphyritic rock just described as occurring in fragments, but in others contains numerous and large quartzes, and exhibits in its purple groundmass a curious mottling of a light grey colour, which is suggestive of a flow-brecciation. Possibly we may be here just on the edge of the lava-flow, and the mass may be more or less a true pyroclastic rock. The outcrops between the Swanymote Rock and Cademan Wood are fairly compact ashy grits, one of which contains occasional quartzes and felspars.

One feature of these volcanic materials, whether lavas, agglomerates, or tuffs, is rather remarkable. This is the absence in the larger masses of any very determinate characters. In those now considered to be lavas, the lath-like microliths, so common in ordinary trachytes, are never more than very imperfectly seen, and they are often wholly wanting. Fluidal, perlitic, and spherulitic structures have not yet been found. In the fragments in the agglo-

* Referred to in former papers as being "near the last letter of the word Swanymote" on the one-inch map.

merate, the first is not often suggested, and it is never conspicuous. A spherulitic structure, not indeed very distinct, has once occurred, and this is in a pebble, obtained only in 1890, from one of the bands of conglomerate at Hanging Rocks.

The exterior of the fragments is seldom at all scoriaceous; often, especially in the larger, it is quite smooth. In the examination of some ten dozen slides of pyroclastic rock from Charnwood, Professor Bonney has never come across a fragment which was indubitably vesicular. This seems indicative of a rather general absence of water from the volcanic foci which supplied the materials *.

5. *Bardon Quarry.*—During the past ten years the great quarry at Bardon Hill has been much enlarged. The owners have afforded us every facility on each of our visits; but in so busy a place minute examination is rather difficult, and we have never found ourselves able to be there when the workmen were absent. At the present time (1890) the quarry is divided into three stages, the lowest and smallest of which has been opened since 1880. It lies rather on the northern side of the common axis of the quarry. The points which were chiefly studied during our visits were—(i.) the order of occurrence of the rock masses, (ii.) their nature, whether indurated pyroclastic or somewhat altered igneous rocks.

As regards (i.), we are now convinced that formerly we mistook the significance of the "shaly bands," in regarding them as indicative of bedding. Further examination in the light of new knowledge has satisfied us that these schistose beds are only "crush-bands," where the rock has yielded to exceptional pressure. This has produced a rude cleavage, on the surfaces of which a filmy micaceous mineral has been rather largely developed, probably at a subsequent period, by the percolation of water †. But, fortunately, this error does not very seriously affect our description of the pit ‡. We then regarded these bands as indicating a general dip of the beds to a point a little N. of N.N.E., but now, so far as we can trust the indications of succession, we consider the dip to be very nearly north.

(ii.) At each visit we carefully recorded our impressions as to the nature of the rocks and their apparent succession. To describe these in detail would be tedious, and perhaps needless; therefore we content ourselves with a summary of the results, requesting future visitors to remember that not a few of the data on which our conclusions are founded have disappeared concurrently with the extension of the excavations.

To the south of the middle pit rises the knoll of breccia described in our papers for 1877–78. The matrix is a volcanic ash, containing fragments of slate, mostly purple, but sometimes greenish in colour, which vary in size, but are occasionally over 1 foot long, and in one

* See Professor Judd's suggestive remarks on the lavas of Krakatoa, Geol. Mag. dec. iii. vol. v. (1888) p. 684.

† On the southern side, in 1889, we were able to examine a part where the rock had been less severely crushed, and found that it was really identical with the brecciated rock of that part of the pit.

‡ Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 780.

case more than 2 feet. A rude cleavage affects the fragments as well as the matrix, dipping approximately at about 60° to a point a little N. of N.N.E. This mass, as indicated in our section *, underlies the rocks of the quarry. A little distance south of the edge of the same pit, and about 70 yards from this knoll, are (at present) outcrops of another rock more or less brecciated. In one reef just close to the edge of the pit-wall an agglomeratic character is very distinct, the fragments, by weathering, standing out from the matrix. Freshly broken surfaces exhibit a mottled structure, which somewhat reminded us of the Kite-Hill rock †. To this succeeds a brecciated rock, now well exposed in the south wall and adjacent floor of the quarry; fragments, sometimes 4 or 5 inches in diameter, of a speckled rock occurring in a dull greenish matrix, from which they are distinguished by the pinker, redder, or sometimes slightly yellowish tint of their ground-colour. This rock seems to pass up—no hard-and-fast boundary being determinable—into the compact, green felstone-like rock, which was chiefly quarried in the older workings. Over this comes a brecciated rock, in which the apparent fragments are parted by a compact streaky matrix of a purple-red colour. To this succeeds another brecciated rock in which a green or yellowish-green colour predominates, which is followed by another breccia, pinker in hue. This last seems to pass into a dull purplish rock, which is rather fissile, and resembles generally the Sharpley porphyroid, especially that variety which is exposed in the knoll on the moor near Spring Hill Farm, except that the quartzes and felspars are rather smaller in size. This porphyroid, in the upper part, has a very ashy look, and contains fragments which sometimes are numerous. Most of these are typical Peldar rock, but a few are a purple porphyritic felstone, and over this porphyroid comes the main mass of rock, identical with that of Peldar Tor.

The nature of the last-named has been already discussed. If, then, it be a volcanic rock, we have to investigate the underlying porphyroid. This rock appears to be rather variable in thickness, and to pass almost imperceptibly into the more or less brecciated greenish rock in which the greater part of the excavation is made. Was it originally a lava or an ash? If the former, the presence of fragments of Peldar porphyroid in its upper part must be explained by supposing it to have broken through a mass of that rock; but on that hypothesis it is a little difficult to account for the occasional association of the purple porphyritic felstone. The distribution also of the Peldar fragments in all the masses which we have examined, while not absolutely incompatible with the above explanation, certainly accords better with the idea of a pyroclastic origin ‡. Microscopic examination of the matrix does not help us very much. The rock evidently has been subjected to considerable pressure. The

* *Op. cit.* p. 780.

† The microscopic structure also is rather similar.

‡ They may have been ejected from the vent which supplied the lava, and have fallen in advance of it—the Sharpley lava and tuff coming from a neighbouring vent.

usual filmy "sericite" has been produced. It contains crystals of felspar, sometimes well developed, sometimes rather rounded in outline or cracked. We find also the usual greenish, black-spotted minerals *. Of the two specimens examined microscopically, one closely resembles a specimen of Sharpley rock, except that quartz grains are practically absent; the other exhibits a more granular structure, rather suggestive of a fragmental origin, and in it aggregated patches of a granular mineral, giving rather rich tints of pink and green with the two nicols, are not uncommon; these, in some cases at least, appear to replace felspar †. Subangular patches also of a brownish mineral are not rare, which has rather weak depolarizing action, and is speckled and bordered with dots of brown iron oxide. This in places seems to be composed of aggregated folia, resembling an altered mica, or more probably a chlorite. Their outline is not sufficiently definite to give any real clue to the mineral which has been replaced. Almost certainly it was a ferro-magnesian silicate, possibly biotite, but more probably a member of the pyroxene group. In the microscopic structure of the rock there is nothing incompatible with its having been a tuff, but there is nothing to *prove* it—no confused association of constituents, no bits of indubitable scoria; in short, no definite structure can be detected. But taking all circumstances into consideration, especially the field evidence, a pyroclastic origin seems the more probable one; that, in any case, the rock is closely related to the porphyroid of Sharpley we think may be safely assumed.

We pass on to the brecciated rocks, in which the quarries are chiefly opened. Here we seem to find almost insensible gradations from the compact felstone-like green rock to rather coarse breccias, which sometimes are also green (fragments and matrix differing slightly in tint), sometimes, as has been said, contain fragments of a colour more or less buff or pinkish.

That the structure of these rocks has been to some extent modified by subsequent pressure seems incontestable, but the effects of this do not generally appear to be very conspicuous. The purple-streaked breccia most resembles a crushed rock, but microscopic examination certainly does not negative the hypothesis of a pyroclastic origin. This is favoured, by both microscopic and field evidence, in the case of the outcrops already mentioned to the south of the middle pit, and by some formerly seen east of the upper pit (at present, we believe, quarried away), while the rocks near the summit of the hill, which now seem to be nearly on the same line of strike, are certainly agglomerates. Microscopic examination of the breccia from the pit itself has not helped us much. That the materials have an igneous origin is beyond doubt; that the whole, if this be a clastic deposit, is practically from the same source; that in it we have as yet failed to find bits of indubitable ash, which are common

* See page 81.

† I have little doubt that they belong to the zeolite group, but think it safer not to attempt to name them. To do this would involve a long investigation, which, for my purpose, would be a waste of time.—T. G. B.

in many of the volcanic breccias of Charnwood Forest, is certain. The structure might be explained by flow-brecciation, but there is nothing to suggest this, and the absence of any fluidal structure in the matrix is opposed to this hypothesis. Though indications of some mechanical disturbance can be perceived almost everywhere, and brecciation may be occasionally due to it, those usually significant of the crushing *in situ* of a large mass of rock are certainly not common. The "shaly bands," of course, prove mechanical action; but our examination of the less crushed portion (on the southern side of the pit) convinced us that the breccia had practically arrived at its present condition prior to the crushing. This appeared to be due to the same cause as that which produced the rough cleavage more or less perceptible throughout the mass.

On the whole, after examining several carefully selected specimens, we still incline to the view of a pyroclastic origin for the main mass of Bardon Hill, while we would not exclude the possibility of some portions being small flows of true lava. The fact is, as we stated long ago, that the micro-mineralogical changes—the devitrification, and subsequent decomposition, the formation of viridite, epidote, &c.—have so "blurred" the structures as to leave us always in a state of uncertainty as to the right interpretation *.

We are not aware that any analysis of the Bardon rock has been published; therefore the following, kindly made for us by Mr. Lord in the laboratory of University College (London), may be interesting. The specimen selected represents the compact green rock, without brecciation, which, as mentioned above, has the closest resemblance to a felstone. Evidently, like the rocks of the Peldar-Sharpley region, it is rather intermediate in character, and nearer in composition to an andesite than to a sanidine-trachyte. It is rather more acid than the Markfield "syenite," and less so than that from Croft Hill.

| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | CaO | MgO | $K_2O$ | $Na_2O$ | Total. |
|---|---|---|---|---|---|---|---|---|---|
| No. I.... | 59·86 | 16·00 | 4·47 | 3·64 | 8·06 | 3·90 | 1·20 | 2·60 | 99·73 |
| No. II.... | 59·00 | 16·00 | 4·50 | 3·70 | 8·00 | 4·20 | 1·36 | 1·84 | 98·60 |

Loss by drying and ignition not estimated.

There have been shown to us some small portions of copper-ore found in quarrying, which contained apparently, with malachite and cuprite, a little native copper. A vein of jasper has also been met with.

* The structures frequently present considerable resemblance to those of the Peldar-Sharpley porphyroid, but the rock seems to be less quartzose; beyond this there is nothing that calls for very special notice. The rock of Birchwood Plantation, a greenish felstone-like rock (noticed in vol. xxxiv. p. 206), presents difficulties similar to those of the more compact variety of the rock in Bardon Pit. In one place it is very like a felstone; in another a structure appears faintly outlined which does not resemble a result of crushing, and suggests a pyroclastic origin.

## III. Additional Notes.

6. *Stable Quarry, Bradgate Park.*—We stated in a former paper that we felt some uncertainty as to the relations of the rocks in this quarry, and further study made us yet more doubtful. So we again examined the quarry in 1890, with the following result:—

The mass of the rock, as already stated, is a quartzite; this also, on the southern side, is clearly intercalated in thin bands in a purplish-brown slate several feet in thickness, exactly as lenticular seams of sand might be intercalated in a mud; the change from the one to the other being very rapid—so distinct indeed that, in a hand-specimen, a pin-point could be placed on the junction of the two rocks. The grains in the quartzite are remarkably well rounded; this peculiarity is most conspicuous in immediate contiguity with the slate, probably because here less secondary quartz has been deposited. The beds are practically vertical, and the average strike is about E. and W. Our former measurement gave it as a few degrees S. of W.; our last measurement, at a different place, a very few degrees N. of W. Towards the northern side there is some appearance of an infolding of slate-bands; but, if this be so, we now regard it as local, and think that in the main the pit gives a regular succession.

The point, however, on which we had become most doubtful was the nature of the rock described in our paper as a "spotted slate," a "pinkish-green felsitic rock with ill-defined dull-green chloritoid (chloritic) spots, the sort of rock that we might expect to result from the re-arrangement of a fine ash or the denudation of a not very acid lava" *. Further study of its microscopic structure suggested both doubts as to the rock being altered, as we supposed, by contact-metamorphism, and the possibility that it might be a dyke, consisting of small crystals of felspar and a pyroxenic mineral, embedded in a rather basic matrix, which had been much modified by crushing and subsequent mineral change. The following is the result of our observations:—

The rock—about 4 feet thick—is distinctly cleaved, though less fissile than the rest of the slate in the pit. From this it differs somewhat in colour, in the presence of the green spots, and in a more "ashy" texture, so that, if a sediment, it must be formed of different materials. But instead of being, like the slate, continuous with the quartzite, the two rocks separate, and the common surface is slickensided, thus indicating the crushing together of distinct and different masses. On the northern side a thin wedge-like piece extends from the main mass into the quartzite. This might be explained as either a lenticular band of mud in sand, or an offshoot from a dyke, but here also is so much disturbance that no definite evidence can be obtained. The microscopic structure is very obscure; probably there have been many small crystals of felspar, now replaced by earthy matter mixed

* Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 763.

with numerous (micaceous ?) films, giving bright colours with polarized light. These are accompanied by irregularly outlined patches of a green mineral, now a mass of flakes, acting little on polarized light, perhaps belonging to the chlorite group; they are scattered in a groundmass of felted and slightly foliated structure, composed chiefly of brown earthy material and filmy viridite.

If this rock had a fragmental origin, the materials must have been volcanic, and the felspar and pyroxene chiefly clastic, but it bears some resemblance to the rock of a dyke which occurs at no great distance in the bed of the neighbouring stream. This, if much crushed and subjected to more micro-mineralogical change, might, we think, present a very similar appearance. We have also compared the rock with an undoubted slate-band which occurs at a distance of a few feet to the south. The latter has a very different structure. It consists of tiny fragments of clear quartz more or less angular, felspar (?), mica, and iron-oxide, embedded in an earthy granular matrix, stained more or less with ferrite and a little viridite. Some chlorite which occurs here and there in streaky patches is authigenous, but the white mica, at any rate, is allothigenous. In short, the rock is like many very old slates, and, according to Professor Bonney, resembles the workable slate of Groby Quarry more closely than any other one in his collection from Charnwood Forest.

From the above considerations, it seems probable that we were wrong in attributing the peculiarity of the "spotted slate" to contact-metamorphism, and that it is more likely to be a dyke, which has been exceptionally crushed and subsequently altered; but it is impossible, with our present knowledge, to speak more positively.

7. *The Igneous Junctions.*—We described, in 1877 *, some sections in Steward's Hay Wood, as proving the intrusive character of the syenite. We have nothing of moment to alter in our description, though it would be easy to add to the minor details; but it must be admitted that the supposed altered slate presents some resemblances to the rock at the Stable Quarry, which we are now inclined to consider an altered dyke, and its structure cannot be exactly compared with that exhibited by any other case of contact-metamorphism which we have examined in other districts. Unfortunately, we have had very few opportunities of studying the effects of intrusive rocks on a fine-grained ash, such as we supposed this to have been, so that the apparent anomaly might disappear under more favourable circumstances. Certainly, if the supposed altered slate be a crushed dyke which has undergone much mineral change—the only alternative,—there are some serious difficulties in the microscopic structure and in the relations of the two rocks which call for explanation. However, though we do not abandon our former view, we think it right to say that it now presents difficulties which at that time we did not feel.

* Quart. Journn. Geol. Soc. vol. xxxiii. p. 786.

But if a doubt has arisen concerning this section, additional evidence has been obtained from another quarter. We were led to examine again the neighbourhood of Bradgate ruins, and a specimen which we succeeded in detaching from the block built into one of the walls showed the syenite to be intrusive, and indirectly strengthened the evidence obtained at the little pit on Holgate Hill, by indicating the significance of structures exhibited by its rocks, which had hitherto been a cause of perplexity. As these structures have a bearing on some general questions, they are described and discussed in the paper immediately following the present one.

We found a small intrusive mass of a rock resembling the northern syenite, at the Honestone Quarry, Whittle Hill, in 1890. Since our last visit a pit had been opened at the back of the cottage, in the eastern wall of which we found a rock which at first sight resembled a rotten arkose, and was completely included in the "honestone;" the latter appearing little altered. In a junction-specimen it seems to differ from the normal rock only in being iron-stained, and in containing a much larger number of small grains of limonite (?). The former rock consists of grains of quartz and crystals of felspar—of rather fragmental aspect—in an obviously microcrystalline groundmass; the whole being much decomposed, and so broken as to present a superficial resemblance to an arkose. Macroscopically, this rock most nearly corresponds with the "northern syenites," with which its geographical position would lead us to associate it.

*Larger ovoid body, Whittle Hill.*

On the opposite face of the same excavation the flinty slate exhibited, apparently on a joint-face, two ovoid bodies (the halves) defined by a zone of dusty material, about $\frac{1}{8}$ inch thick. They were about 16 inches apart, the connecting line sloping at about 35°. Their longer diameters were vertical, one about $3\frac{1}{2}$ inches, the other about $4\frac{1}{2}$ inches. The material within and without the ring seemed identical. We cannot offer any suggestion as to their origin.

8. *Brazil Wood.*—In 1890 we again visited the quarry at Brazil Wood. In working for the first of our papers—as will be seen from the remarks and quotations in the final one *—we fear that we rather slurred over this locality, as it had already received so much notice. The result is a useful warning to geologists not to neglect even a *locus classicus* when new methods of investigation have been devised, or the point of view has been materially altered. We may,

* Quart. Journ. Geol. Soc. vol. xxxvi. (1880) p. 349.

however, plead in excuse that some of the most important evidence was disclosed by quarrying subsequent to our visits, and that it is only during the winter and early spring that the hill itself can be readily examined, as it is so much overgrown during the rest of the year by brushwood and coarse herbage.

On the last occasion a dyke of granite, some 4 feet wide, was exposed, running from the top almost to the bottom of the north-western wall of the pit, where it was still concealed by the micaceous rock. There was also another mass, not so well exposed, in the S.W. wall, and the end of a vein just showed itself in the wall between these. We are certain that these junctions were concealed at our visits prior to 1877, and the great dyke was not visible even a year or two later than that date. We were able to examine carefully the knoll at the back of the pit, and found several small low outcrops of the "micaceous rock." For a few yards this does not seem to differ from the rock in the pit; then it becomes less coarsely crystalline, after which a fissile zone occurs *, and about 4 yards farther, at the base of the knoll (which runs roughly N.N.W.–S.S.E.) some thirty yards in a straight line from the edge of the pit, is a purplish slaty rock, which macroscopically does not seem much altered. We have examined, microscopically, specimens of these rocks in order to study the effect of the contact-metamorphism. Commencing with the last-named:—it exhibits a minutely speckled groundmass, consisting of tiny plates of brown mica, of white mica (?) (this is the more abundant mineral, and sometimes is aggregated in small patches with uniform extinction), and of a colourless mineral, probably in part at least quartz; here and there is a larger grain of a colourless mineral, quartz or some silicate. Through the groundmass run trailing aggregates of irregular form, which sometimes enclose small, rather oval, patches of it, and consist of brown mica-flakes from about ·001 inch long, at a maximum, downwards. In one part of the slide flakes are grouped in tiny clusters, more or less circular in outline, round which is a clear narrow ring of the colourless mineral (chalcedonic quartz?); granules of brown iron oxide also occur. The streaky aggregates exhibit a slight tendency to parallelism, but there is no true foliation; the slide, however, exhibits some iron-stained cracks, indicative of a rude cleavage. The specimen on the whole presents a general resemblance to that described from near the contact at Enderby †.

A slice cut from a specimen about ten yards nearer the edge of the pit is more coarsely crystalline, the mica flakes being generally twice or thrice the former size, especially in the case of the white mica, which is now a much more conspicuous object; the peculiar clotted and spotted aspect of the rock is almost lost, and several garnets occur, approximately from ·02 to ·03 inch in diameter. Near the junction the rock becomes yet coarser in texture, the garnets measuring

* The strike of the cleavage is given in Messrs. Allport and Harrison's paper, Mid. Nat. vol. ii. (1879) p. 243, as N.W.–S.E.

† Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 227.

nearly ·1 inch in diameter, and the flakes of mica (especially of the white) sometimes about half this length; but the structure of this part of the altered rock and of the granite has been so admirably described by Mr. S. Allport that it is needless to do more than refer to his paper *.

It is then evident (as stated in our last paper) that the name "gneiss," by which this rock was formerly designated, must be dropped, and, until petrographers agree upon a nomenclature for the products of contact-metamorphism, we may designate it simply "a micaceous rock," for it cannot properly be named a schist. Its slickensided condition, so often noticed, the development in the garnets of cracks and a rude cleavage, and of the latter in parts of the rock, indicate that the intrusion of the granite was prior to the chief earth-movements which have affected the Forest. We did not succeed in finding (but in such a place it might easily be overlooked) any outcrop of sedimentary rock at a greater distance from this pit. We are, however, disposed to conjecture that the latter originally consisted of materials generally similar to those of the slaty series at Swithland and Groby.

9. *The Blackbrook Group.*—Aided by the six-inch map we have found several outcrops previously unknown to us. A long narrow plantation N.E. of Gun Hill, called Strawberry Hill, covers a sort of ridge, in the middle and at the southern end of which rock may be seen; the materials are ash with fragments. A wood called Cat Hill, N.E. of Timberwood Hill, surrounds a steep crest of ashy rock. On the line between these two lie the long narrow ridge of Collier's Hill (in the grounds of Charnwood Lodge) and the crags of the Hanging Stones (Flat Hills). These last contain many fragments. We think our specimens from these localities show some common features; accordingly we regard this group of outcrops as a base to the vast mass of agglomerates which occupy the area of the North-west region. Their line is parallel to another which may be drawn through the outcrops of the Blackbrook Tollgate (Ringing Hill), the old reservoir (Blackbrook Valley), the Oaks Church, and Mr. Dexter's Farm (north of Charley Hall), on which also lies an outcrop north of the railway, altogether a line four miles long. The rocks along the latter line are characteristic examples of what we have called the Blackbrook Group, being entirely unlike those of the North-west region; though they consist mainly of volcanic materials, the constituents are much smaller in size, and of a felsitic nature.

A small quarry, previously unnoticed, in a field east of Charley Mill, contains rock which is of typical Blackbrook character, but it lies half a mile S.W. of this line, and must be displaced by a fault. As, moreover, the rock near White Horse Wood (300 yards west of the White Horse public-house) is indistinguishable from that of the pits at Blackbrook Tollgate (Ringing Hill), but is half a mile N.E. of the line of strike, it is probably the same repeated by another fault.

* Geol. Mag. dec. ii. vol. vi. (1879) p. 481.

We examined the neighbouring rocks on the other side of the anticlinal, but obtained no additional information as to the representatives of the Blackbrook Group. We found, however, a singular rock hitherto unnoticed, a quarter of a mile south of Beacon Lodge, on the west side of the road. It does not precisely agree with anything else in the region, but somewhat recalls the Sharpley rock, and the resemblance is not macroscopic only. Microscopic examination shows it to be composed of fragments of a devitrified rhyolitic rock, exhibiting varietal differences of structure in rather sharp contrast. These contain both crystals of felspar, showing sometimes oscillatory twinning, and grains of quartz. Larger grains of the latter mineral also occur apparently not embedded in the matrix. The rock undoubtedly has been modified by pressure; its aspect on the whole accords better with a pyroclastic origin, but if so, the fragments were not at all scoriaceous. If it is a crushed (devitrified) "obsidian," then we must assume an unusual amount of flow-brecciation.

10. *Fragments and Pebbles.*—Careful notes were made of the nature of the fragments in the agglomerates, in the hope that they might help in classifying the deposits. We distinguished four varieties, designating them for our own purposes as ($\alpha$) "Purple Porphyritic" (rhyolite), ($\beta$) "Compact Purple" (non-porphyritic rhyolite), ($\gamma$) Porcellanous (a "marbled," somewhat vitreous-looking rock *), and ($\delta$) Syenitoid (a mottled rock with a slight superficial resemblance to the syenite of the Forest). The first two are probably different conditions of the same material, and are frequently found together, so that there may be only three groups indicating sources or epochs of discharge. We found that the fragments in any outcrop more often belong to one only of these groups, but frequently two, and sometimes all three, occur together. Slate fragments also sometimes accompany them. The "purple" rock occurs everywhere, and in particularly large masses in the spinneys east of Peldar Tor. The "syenitoid" is the sole variety in the huge "rounded agglomerate" one-third of a mile E.N.E. of the Reformatory. The "porcellanous" occurs chiefly about Gun Hill, Cademan, and the Whitwick-village (Pinfold) Quarry. The "porcellanous" and "syenitoid" sometimes are not easily separated. If we take them together it would appear that the group chiefly occurs either just above and below the Sharpley rock (Gun Hill, Cademan), or on the horizon it appears to occupy (in the "rounded agglomerate"); they do not, however, occur at Ratchet Hill, where an agglomerate is virtually in contact with Sharpley rock. Slate fragments are very local; they are large on the High-Towers Ridge and Swanymote Rock, but occur in few other outcrops, and have not enabled us to add to what we have already written.

* The microscopic descriptions are given, though not under these separate heads, in Part III. referring back to Part II. of our former paper. The names apply only to the general aspect of the rock, and are not of any scientific value. The "syenitoid" has a superficial resemblance to a holocrystalline rock, but is not so really.

We have also paid some attention to the pebbles in the conglomerates which occur elsewhere in the Forest. Felstones and slates are commonest, but true quartzites are found at Forest Gate and Hanging Stones (Woodhouse).

Under the microscope the felstones at the latter place bear a general resemblance to the "purple porphyritic" fragments of the North-west region. The groundmass of one exhibits, in parts, an imperfectly-developed spherulitic structure. A small fairly-rounded pebble of compact quartzite from this locality consists of grains of quartz, commonly more or less subangular, set in a finely granular matrix. For the general aspect of the rock, see Fifth Annual Report of U.S. Geol. Survey, pl. xxxi. fig. 4, lower half. But in the Charnwood pebble the matrix consists of a pale filmy micaceous mineral (abundant) mingled with minute chalcedonic quartz. The rather "ragged" outline of the quartz grains indicates enlargement *in situ*. The rock reminds us more of some Huronian quartzites than of those of later age.

Another fairly rounded pebble from the same locality is generally similar, but the quartz grains are more numerous and slightly larger, one or two containing very thin colourless belonites. The micaceous constituent also is slightly larger. A grain of plagioclastic felspar can be recognized, and there are two or three small grains of a honey-yellow mineral, giving fairly bright tints with the crossed nicols. A well-rounded pebble from the ashy rock at Forest Gate consists of quartz grains, as above, one or two containing belonites, with some secondary enlargements, but there is little "matrix." A few grains suggest decomposed felspar, and the rock is more ferrite-stained than in the other case. All these pebbles may very well have been derived from different parts of the same rock-mass.

11. *Glacial Phenomena.*—During our work in Charnwood Forest we did not attempt any precise record of the distribution of erratics or other glacial phenomena; but as we were not unmindful of the question, the general results of our impressions may be of interest. The ordinary signs of the action of glaciers, so far as we have seen, are wanting in the Forest, while the forms of the crags on Cademan, Peldar, Ratchet Hill, and Sharpley, or indeed in any other part of the Forest, are such as to prove that they either have never been moulded by the action of ice, or have now lost all traces of it. The northern part, indeed, of the Sharpley ridge might be called a model, on a small scale, of a group of Alpine *aiguilles*. Again, we have frequently seen old surfaces of very hard rock, as at Bardon Hill, or near the Groby syenite-quarries, or at Mount Sorrel, exposed by removal of the protecting soil. In no case have we seen a characteristic ice-worn surface*. Now and then a few inches

* We cannot agree with the opinion expressed by Mr. H. E. Quilter (Mid. Nat. vol. vi. p. 237) that the diorite near Brazil Wood gives indications of the action of land-ice. He states that he saw a junction between the diorite and the granite; this we have not noticed.

of rock appear to have been rubbed away from the crests of a series of small ridges; but commonly the ridges are sharp. Hence we seem entitled to assume that, if ever an ice-sheet came so far south in England, it did not pass over the Charnwood Hills. Boulder-clay, however, has been occasionally seen in outlying places, as at Mount Sorrel and Croft Hill, resting on the granitic rock. But erratics of local rocks have evidently been distributed both over the Forest and from it as a centre. For instance, over the low ground, in the valley N.N.E. of One Barrow Farm, we noticed a scatter of erratics of ashy rock, among which was one boulder of agglomerate (full $4' \times 3' \times 1\frac{1}{2}'$), which appeared to correspond with those which crop out on Gun Hill, from which a shallow depression comes down to the valley. On Bardon large blocks are scattered in a sort of "head," overlying a patch of Keuper, rather more than 650 feet above the sea; these must have come from the upper part of the hill, and there has evidently been a scatter of blocks from Peldar Tor and the neighbouring region over the lower ground to the west. They lie, where the soil is thick and no rock can be near the surface, at distances and in positions to which they cannot possibly have rolled from any crags now visible. In short, there is frequent evidence of a considerable scatter of fragments over the Forest region, which we can only attribute to the action of ice. Further, the Reports of the Erratic-Blocks Committee of the British Association prove that the Forest has been the centre of a considerable and extensive dispersion*. The granite of Mount Sorrel has been identified resting on the surface, or lying in Upper Boulder-clay at elevations ranging from the bed of the Soar Valley, *i. e.* about 150 feet above the sea, up to as much as 280 feet above it. Blocks of the "southern syenite" have been observed about 4 miles away to the south, and 210 feet above the sea. The rock is scattered over a considerable area to the S.E. of the present outcrops at Groby and Markfield; and the Mount-Sorrel granite with other Charnwood rocks may be recognized in boulders at various places over a region extending from Leicester to Coventry and from the latter town to Stockton†.

From the above evidence it is clear that during the time of the Upper Boulder-clay Charnwood Forest was an independent centre of dispersion for erratics, which, especially in a S. and S.W. direction, reach more than 20 miles away‡. The vertical limits already mentioned make it very improbable that the ground has been overflowed by a northern ice-sheet; large local glaciers are out of the question. Hence transport by coast-ice during partial submergence seems most in accordance with the facts; and if the Boulder-clay were a terrestrial formation, what explanation is to be given of the cetacean bone which has been discovered in it§?

* See Reports of Committee: Brit. Assoc. Report, 1883, 1886, 1888.

† Tuckwell, Brit. Assoc. Report, 1886, p. 627.

‡ I observed, in the autumn of 1889, blocks of more than one kind of rock (among them syenite), which appeared to me to be from Charnwood, built into the very ancient masonry of Brixworth Church.—T. G. B.

§ Brit. Assoc. Report, 1888, p. 124.

12. *Age of the Clastic Charnwood Rocks.*—Since the publication of our papers a considerable amount of evidence, which has an indirect bearing upon the question discussed in this section, has been brought to light by the investigations of Professor Lapworth and Mr. W. J. Harrison in the Hartshill and Dosthill district, and of Mr. E. Brown in his examination of the Permian breccias of the Leicestershire Coal-field. The occurrence of Cambrian rocks in Warwickshire has been proved by the evidence of fossils, and these overlie a quartzite of considerable thickness, under which is a volcanic series. The last, however, does not, in our opinion, closely correspond with the Charnwood rocks of similar origin, but appears more nearly to resemble the volcanic groups beneath the quartzites at the Lickey and in the Wrekin district. In the last-named it has been demonstrated that the quartzites cannot be newer than the very lowest member of the Cambrian age*. The attempts to link within that system the volcanic groups at St. David's and of the Bangor-Llanberis district have not, in our opinion, been successful. Hence it seems more in accordance with the usual principles of geological nomenclature to separate these volcanic deposits from the Cambrian, and place them all provisionally in the system for which Dr. Hicks has proposed the name "Pebidian." As to the magnitude of the break between the two, it is difficult, at present, to express a positive opinion; it may not have been greater than that between Ordovician and Silurian, but their physical conditions appear to have been very different. The Pebidian period was characterized, in the districts hitherto recognized in Britain, by considerable volcanic activity, so that not only agglomerates and ashes are abundant, but also even the finer slates suggest the presence of large amounts of volcanic dust. These materials no doubt were often spread out and modified by the action of water, but probably the sea was shallow and interrupted by land in the above-named region. The Cambrian period, however, appears to have been one of steady, continuous depression, during which the older land-surfaces gradually disappeared beneath the waves, so that beds of a much more uniform and ordinary sedimentary character were deposited. The Charnwood Group, as we formerly stated, presents resemblances to the volcanic Ordovician rocks of the Lake District, but the tendency of the evidence since we wrote appears to us strongly in favour of referring the Forest rocks to the latest epoch in the pre-Cambrian series—the Pebidian.

13. *Age of the Igneous Rocks.*—The paragraph on this subject in Part. II. is of course cancelled by our reference of the sedimentary rocks of Charnwood to a Pebidian instead of an Ordovician age. We are not indeed prepared with any other suggestion, but may say that it seems probable that at any rate the larger masses of igneous rocks were intruded prior to the earth-movements which

* They are assigned by Professor Lapworth to the base of the *Olenellus* zone ('Nature,' Dec. 27, 1888).

impressed a cleavage on the finer-grained stratified rocks *. Diorites were intruded into Cambrian rocks, probably before the Carboniferous period, in the Hartshill district, but these have no particular affinity with the larger masses in the Forest. Certain fragments in the Permian breccias of Leicestershire indicate the existence of red felstones somewhere in the neighbourhood, which do not correspond with any now visible above ground. It is, indeed, very possible that intrusions of melted rock occurred at several epochs, terminating with the post-Carboniferous basalt, such as that found in the Whitwick pit-sinkings, and that the igneous rocks of the Forest are of more than one age; but beyond the statement that we think the above-named masses anterior to the great earth-movements which seem to have affected a very large area of the Midlands, we feel unable to venture †.

14. *Corrigenda.*—Had we to rewrite our former papers, we should make many small changes in phrases and words. For instance, the epithets "blue" and "bluish" used of various rocks should rather be "purple" and "purplish." "Schist" and "schistose" have been used very loosely in Part I. ‡ The improper designation of the Blackbrook Group as "quartzites" was corrected in Part III. This was inherited from previous writers on Charnwood; so also were many phrases which describe the rocks as much metamorphosed, or as if they had suffered great changes by the action of heat. In one case, however, where the rock is described as "intensely altered" § the specimen on which the description was founded turns out to have been broken from an included fragment, so huge as to have been mistaken for the natural rock.

Mistakes are fortunately not very numerous. In Part I. p. 755, line 7, "North-eastern" should be "North-western"; p. 762, fig. 1, "Branch" is an uncorrected misprint for "Brande." In fig. 2, the

* As at Brazil Wood, at Whittle Hill, Bradgate, and possibly at Steward's Hay; also (if the rock be a dyke) at the Stable Quarry, Bradgate. Mr. J. D. Paul, in a good report of a visit of the Geologists' Association excursion to Charnwood (Proc. Geol. Assoc. vol. x. (1888) p. 472), says that Charnwood presents in miniature all the features of a mountain-chain, and generalizes from the fact that the outbursts of intrusive igneous rock occur at a considerable distance from the anticlinal and near the foot of the hills. But the vertical difference is hardly enough to warrant any generalization, and the intrusive rocks appear to us more probably anterior to the 'mountain-making.'

† Mr. W. J. Harrison expresses the opinion that the 'syenite' at Enderby is intrusive in beds probably of Cambrian age. His view may be correct, but we have seen nothing to separate the rock described by us as occurring there from some of those in the Forest. He also states that the rock struck in the Orton boring appears to be identical with the quartz-felsite of the Caldicote Pit, Nuneaton. To us the two rocks appear dissimilar. The Orton rock, however, is indistinguishable from the Sharpley rock, both macroscopically and microscopically, except that we had less hesitation in recognizing it as a true lava. This is a point of great interest, for it shows the occurrence of another (probably contemporaneous) volcano, and greatly extends the area affected by the pre-Carboniferous earth-movements. Orton is more than 30 miles S.E. of Sharpley, and about 25 miles from the nearest point of the Forest.

‡ Quart. Journ. Geol. Soc. vol. xxxiii. (1877). § *Op. cit.* p. 778.

slate represented in contact with the syenite of the ruins is an error. The discovery of a grit-bed communicated to us, and mentioned on p. 760, line 47, was announced, as we have since learned, on insufficient evidence. The "greenish slaty ash," described as on the top of Nanpanton, must have referred partly or wholly to what was afterwards recognized as "greenstone." Fig. 1 in Part III. represents the "Sharpley Rock" as if faulted against "coarse agglomerate." For this there is no authority; the mistake was unaccountably made in engraving the woodcut, and unfortunately slipped through the press unnoticed.

In working for our former papers, we had only the one-inch map. It may assist visitors if we add the following table of names used by us, which are absent from or changed in the new six-inch map:—

*Blackbrook Tollgate*, now Ringing Hill.

*Blores Hill.* A spinney in a field N. of Bradgate Park; now Warren Hill.

*Broad Hill.* The name was used for some outcrops now unnamed, but marked, in a field 300 yards W.N.W. of the wall round Ratchet Hill.

*Hanging Rocks*, near Woodhouse. Marked on the one-inch map as Hanging Stones, and on the six-inch as Hanging-Stone Hills.

*Hanging Stones*, east of the Monastery. Now Flat Hills, one spot being marked as "the Hangingstone."

*High Towers.* The moorland E. of the Forest-Rock Hotel. Now Warren Hill.

*Holgate Hill.* In Bradgate Park, E. of Old John Hill. Now unnamed. The name is now applied to a spinney beyond the park-wall, but is spelled Hallgate.

*Kidney Plantation.* East of Lubcloud, west of Round Hill. Unnamed.

*Moorley Hill.* Unnamed. The quarries are indicated 700 yards S. of Sheepshed Station, E. of Morley Farm.

*New Cliff.* Now Newhurst Plantation.

*Stable Quarry*, in Bradgate Park. A pit in the knoll across the brook, S. of the ruins. The buildings were pulled down some forty years ago, and the name may be of our own coining, but it is convenient for reference.

*Steward's Hay.* Now Bradgate House.

*Steward's Hay Spring.* Unnamed. The shallow pit with quartz-grit is faintly indicated in the west corner of a field, bounded by Ladyhay Wood on the east, and the woods round Bradgate House on the north.

*Tin Meadow.* Unnamed. In our papers the name is used to denote a spot $\frac{1}{4}$ mile N. of the Forest-Rock Hotel.

## 9. Note *on a* Contact-structure *in the* Syenite *of* Bradgate Park.

By T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S., Professor of Geology in University College, London, and Fellow of St. John's College, Cambridge. (Read January 7, 1891.)

Built into a wall at the ruins, Bradgate, is a block which exhibits a clear junction between the "syenite" and a pale green argillite. Microscopic examination of a fragment which we contrived to detach throws light on an apparent anomaly and offers some suggestions of a wider bearing. The argillite, though in contact with a rock apparently rather coarsely crystalline, is only converted into a natural porcelain; it is "baked" rather than "metamorphosed." Is this due to the refractory nature of the materials or to a comparatively low temperature in the intrusive rock? Microscopic examination shows that within a quarter of an inch of the actual junction the argillite does not materially differ from one of the "flinty slates" common in the Forest. If a slice were cut exclusively from this part it might be passed over without any suspicion of its proximity to a contact-surface. The syenite, macroscopically, is slightly finer in grain, and less definitely mottled with dull green than the normal rock, but on microscopic examination it exhibits some important differences. The line of junction of the two rocks is slightly wavy; for about ·02″ to ·04″ the argillite is darkened, and one or two tiny roundish patches occur, occupied by viridite and chalcedony (?), which may possibly be minute cavities subsequently filled. The intrusive rock has at its margin an ill-defined zone, about ·06″ wide, consisting of a microgranular matrix, in which are many small fragments (apparently of felspar and possibly of quartz), very like one of the more gritty bands which may be seen in the slate on Target Hill. To this succeed crystals of felspar and grains of quartz, say about ·04″ in diameter, of which the former sometimes exhibit regular crystalline outlines, sometimes seem to be fragmental and scattered in a matrix, described below. These increase so rapidly in number that at least half the slide is occupied by them. The minor interstices are occupied by viridite, but the larger exhibit the "speckled" devitrified structure so common in lava-fragments from the Forest agglomerates and in the Sharpley rock. In one or two, however, somewhat ill-defined, lath-like crystallites of felspar occur, such as may be seen in many trachytic rocks, and these sometimes exhibit an approach to a spherulitic grouping. The figure on the next page (1) is a careful drawing from the most conspicuous instance, and the diagram (fig. 2) gives an idea of the relative proportion of matrix and crystals.

A comparison of the structure described above with that generally presented by the "syenite" in other parts of the Forest * seems to

* See Hill and Bonney, Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 211, and Mr. Teall's fuller and improved description, 'British Petrography,' p. 270, &c.

throw light upon some general questions in the history of igneous rocks belonging to the more acid division.

The consolidation of a rock may be regarded as a function of three variables, more or less independent, these being heat, water, pressure. The usual effect of a falling temperature is probably greatly modified by the second and third; so that, in nature, the order of consolidation of minerals from a magma may vary much

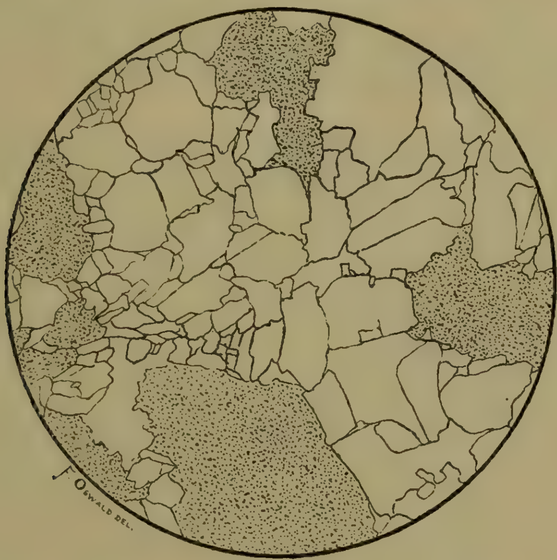
Fig. 1.—*Structure of "syenite" close to junction, from Bradgate Park. The larger grains are quartz and felspar* (× *about* 30).


from that of an anhydrous mass, otherwise of like composition, and, in the process of cooling, variation in the amount of pressure or water may produce apparently anomalous or contradictory results *.

* Many of the remarks made in this paper are obviously not new. But, as I have stated nothing which I have not observed for myself, and have had the subject constantly present to my mind since 1877 (see my paper 'On certain Rock-Structures as illustrated by Pitchstones and Felsites in Arran,' Geol. Mag. dec. ii. vol. iv., and my Presidential Address to the Society in 1885), I have not attempted to stud these pages with references to the works of others, or to devote hours of search through books in endeavouring to ascertain whether a particular idea was published by myself before I could have had it suggested by the writings of another. I have not read any paper which has treated the subject

Thus, for instance, a mineral (*e. g.* a felspar) may be formed in a magma, but afterwards, even though the latter continue to lose heat, may be dissolved by increase either of pressure or of the amount of water present *. At one time, for example, quartz may separate before felspar from a magma, at another, as is more usual, the reverse may occur. Still, as is well known, in most cases a fairly definite order of crystallization exists, and in a holocrystalline mass those which first form are obviously the most idiomorphic.

Fig. 2.—*Diagram illustrating relative amounts of quartz and felspar and of matrix in "syenite" from Bradgate Park* (× *about* 20).



A rock may be either a glass or not a glass. If the latter, it may be (according to the usual division) cryptocrystalline, microcrystalline, or crystalline. The second and third practically pass into one another without any real break, the difference being mainly one of size, but perhaps sometimes of completeness in the segregation of the mineral constituents. Very possibly the first also passes into the second; here, however, differences in completeness of segregation are apparently more significant than those in regard to size. Moreover, a porphyritic structure may or may not exist in every igneous rock. It may be microporphyritic (if a glass) or macroporphyritic. Actual size hardly can be said to matter, so long as one or more minerals are markedly larger than those associated with them. Hence, if, after any one mineral had formed in a magma, the tem-

from quite the same point of view, but I may mention that I am conscious of help, direct or indirect, from papers by, and conversation with, Prof. Judd. Mr. Iddings' most valuable memoir 'On Obsidian Cliff, Yellowstone Park,' and that by Dr. Hatch 'On the Spheroid-bearing Granites of Mullaghderg,' Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 548, contain many useful remarks and references.

* See the suggestive remarks by Prof. Judd in the Krakatoa Report, p. 42, and Geol. Mag. dec. iii. vol. v. p. 1, and the excellent summary of Lagorio's results by Mr. Teall, 'British Petrography,' p. 397.

perature were rapidly lowered and the process of crystal-building stopped, the result would be a porphyritic rock; while if it were slowly cooled this structure might not be developed. It is evident sometimes that the porphyritic structure has been set up during the final consolidation of the rock, as for example in a dyke, where the crystals are wanting near its exterior, set in gradually, and get larger towards the middle; sometimes it is no less evident that these crystals belong to an earlier stage in the history of the rock, and that, whether lava-stream or intrusive mass, it consisted, on assuming its present position, of solids (*i. e.* crystals) embedded in a more or less viscid fluid. The latter may have been in any condition, from a nearly perfect liquidity to one like that of putty or cooling tar. But at this stage the crystals previously formed may be exposed to strains, and so are liable to be fractured. Of course, the temperature of the mass, *ceteris paribus*, will be then comparatively low.

Now it is obvious that the readiness with which a glass is formed depends not only on the circumstances of cooling, but also on the composition of the magma; *e. g.* large masses of glass are very rare among the more basic rocks, and perhaps unknown among peridotites. Moreover, among the acid rocks, we find that in some the glass is comparatively free from microliths, while in others it is crowded with them (felspar usually), sometimes to such an extent that the presence of a vitreous base can only be demonstrated in very thin sections. Suppose, then, a mass be cooling, which is composed of crystals, some of which are felspar, scattered throughout a magma which consists of the constituents required in forming a felspar, together with an excess of silica. This magma in certain cases may solidify as a glass; in others the felspar may be gradually separated, until ultimately the residue is silica, which will then crystallize as quartz *. Now this differentiation of the magma may take place in any of three ways:—(1) The felspathic constituents may be added to the felspar already existing, and the residue crystallize as interstitial quartz, which may be sometimes of considerable size †. This process supposes considerable freedom of molecular movement: that is, probably, a very slow change. (2) In some cases the magma (probably if it is abundant) may set up an independent holocrystalline structure (as is the case in most porphyritic granites), in which, as a rule, the smaller felspars are also idiomorphic. (3) In other cases the felspar, though it separate from the quartz and crystallize, may be forced, as it were, to include the quartz; still both the one and the other, though each forms a kind of lattice-work

* Of course I do not forget that water is present, but as this has no direct bearing on my line of thought (though it is a most important factor) I do not mention it.

† In some cases we find little grains or even vein-like masses of a felspathic mineral which appears to have been occluded from the quartz. In this case probably the felspathic constituents were not perfectly segregated from the residue when free molecular movement became impossible. But sometimes the felspar forms with the quartz a structure which might be called 'ophitic,' the quartz being analogous in its mode of occurrence to the augite in this variety of dolerite.

crystal, may be for a considerable distance practically a single crystal. This, I take it, is the case where a spherulitic or "graphic" structure is set up. These last structures, then, seem to indicate that the temperature of the mass was comparatively low, but that it fell very slowly. Its constituents, so to say, have ample time to arrange themselves, but the magma is not sufficiently fluid to permit of the molecules travelling for any distance. We may illustrate it by a tightly-packed crowd, where individuals already almost touching one another may contrive to get together into little knots, but when this is done these knots are effectually isolated one from the other. Further, the larger crystals of felspar which already exist form, as it were, rallying-points for the felspathic constituents in the neighbouring glass; or, to speak more exactly, the formation of crystals—as is well known—is promoted by the presence of solids, especially when these are of like composition. So we find that most (perhaps all) rocks which exhibit a micrographic * structure are also porphyritic. In this case we frequently observe that the porphyritic felspars are no longer, strictly speaking, idiomorphic; for their crystals pass abruptly into a "graphic" growth of felspar, separated by quartz. Sometimes, indeed, we observe that the original, commonly idiomorphic, felspar can still be detected by some difference in its optical characters or amount of decomposition. About this has been formed a zone of felspar, apparently not always quite identical in composition, and this zone throws out root-like prolongations, which are sometimes, but by no means always, in optical continuity with it. Probably this diversity of habit is mainly determined by accident, which favours the starting of this growth at particular points. The wedge-like outline frequently assumed by the felspar in rocks with a micrographic structure is probably due to the attempt on the part of the mineral to assume an idiomorphic form. The less regular shapes, such as the branching or root-like varieties, may be due either to the resistance offered by the almost solid (and crystallizing silica), or in certain cases to some slight movements of the mass in the last stages of solidification †. In relation to this question we may notice that at a junction-surface between a holocrystalline rock and a sedimentary one there is not seldom a zone, perhaps about $\frac{1}{50}$ of an inch wide, in which the felspars seem to spring from the junction-surface and grow inwards, like tufts of grass from the ground.

To come, then, to the case of these "syenites" of Charnwood. As already noticed by myself ‡, and as described in more detail by Mr. Teall §, they are characterized, especially in the case of the apparently coarsely-crystalline masses of Groby, Bradgate, Markfield,

* 'Micropegmatitic' of some authors.

† I must not, however, be understood as pledging myself to the assertion that this structure can only be produced in a cooling mass. There are cases where there is much to be said in favour of its secondary origin. But this is no more than may be affirmed (for instance) of spherulitic structure. (See my Presidential Address, Quart. Journ. Geol. Soc. 1885, Proc. pp. 68, 69).

‡ Hill and Bonney, Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 215.

§ 'British Petrography,' p. 270.

and Hammercliff, by the prevalence of a micrographic structure; that is, they are not really a uniform holocrystalline rock, but a porphyritic rock, with abundant crystals set in a micrographic matrix *. We can thus assign a reason why this Bradgate syenite has so little affected the neighbouring sedimentary rock, while at Brazil Wood the slaty rock is very highly altered near the junction with the granite, and appreciably so when it is last seen at a distance of thirty yards. But the Mount-Sorrel granite is a holocrystalline rock, and continues to be the same at the junction in Brazil Wood; that is, we may assume that either the temperature of the sedimentaries had been so much raised before the granite was intruded that it cooled very gradually, or (what is perhaps only another way of stating the same thing) that the granite was at a very high temperature. At any rate, the fact that we do not find indications of a selvage to the igneous mass indicates that it did not lose heat rapidly.

But in the Charnwood syenite, mentioned above, we find that a micrographic structure is prevalent throughout the mass, and this, near the junction, is replaced by an ordinary "trachytic" structure or by one which seems to indicate the devitrification of a glass †. Here also we notice that the embedded crystals are often broken, so that the rock almost presents a fragmental aspect. I infer, then, that this mass was, as a whole, at a comparatively low temperature, and consisted, when it reached its present position, of solid bodies (*i. e.* crystals), amounting to at least half the volume of the mass.

But, as has been said, some rocks are almost uniformly holocrystalline. In connection with this it is interesting to notice a structure which might almost be called characteristic of vein-granites, and is not seldom seen to form a kind of selvage, often not more than ·2″ thick, to a fairly coarse holocrystalline mass at its junction with a sedimentary rock (which is always much altered). In such cases the crystals are rather small; the felspar often is only partially idiomorphic, and sometimes there seems to have been a "neck-and-neck race" between it and the quartz, and the latter has occasionally contrived to win. This produces a sort of mosaic of quartz and felspar, resembling the microcrystalline structure in many felsites, and even bearing some likeness to certain cases of contact-metamorphism in sedimentaries. The minerals sometimes almost dove-

* Among British rocks which afford excellent examples of this structure may be mentioned parts of the so-called 'Dimetian' of St. David's, and of the granitoid rock of Ercal Hill (Wrekin). Formerly, in consequence of certain anomalies in structure, I regarded these as not of igneous origin, but further study and wider experience have convinced me that I was wrong.

† A specimen collected from the little pit on Holgate Hill several years ago, which was believed to be, if not actually in contact with the sedimentary, all but touching, shows a curious mixture of 'trachytic,' subspherulitic, and imperfect micrographic structure. One lately collected, probably within a yard of the actual junction, shows the micrographic structure, though it is on a very small scale and less regular than in an average specimen of the syenite from Bradgate Park and elsewhere.

tail one into the other, and the felspar occasionally exhibits in the thin sections what are either true inclusions of quartz or sections of lobe-like prominences of that mineral. That is to say, we find in certain vein-granites, though on a smaller scale, the nearest resemblances to a structure which, so far as I know, is characteristic of the granitoid gneisses of the older Archæan. It appears, then, to me that this peculiar structure, which in the case of vein-granites may be traced into the normal structure of granite with fairly idiomorphic felspars, indicates some mode of what I may call "constrained crystallization;" that is to say, the mass did not possess the complete freedom of molecular movement which has existed in the case of a normal granite. Probably at first it lost heat somewhat rapidly, and so rather quickly assumed a "pasty" condition. The same cause—constraint, due to the mass having previously solidified—may explain the peculiar confused indeterminate structure which is more strictly called cryptocrystalline, for, as I have elsewhere shown, both from my own investigations and those of others, it is evident that considerable separation of constituents may take place without actual melting*. Perhaps cases often have occurred in nature where the mass has not even become plastic, but the action of pressure and water, at a low temperature, has caused the constituents to enter into more stable combinations, though only a small amount of molecular movement has been possible. Thus, in some devitrified rocks it is hardly possible to recognize individual crystals, or say more than that some minute quartz appears to have segregated generally from the originally vitreous mass, the residue of which is a silicate, usually, if not always, crystalline, and in most cases a felspar.

### Discussion on the above two Papers.

Prof. Blake was glad to hear that the Peldar-Tor rock was definitely admitted to be igneous. On his last visit to Bardon Hill he had been struck with the evidence of crushing. With regard to what the Authors had inferred to be a pyroclastic rock at Bardon Hill, he believed the same arguments would hold good as those which had been advanced in the case of Peldar Tor.

Dr. Callaway had been puzzled in trying to distinguish pyroclastic rocks from igneous ones in Shropshire. He had not been able to find the slightest evidence of the former presence of an ice-sheet in that county.

Mr. J. W. Gregory called attention to the limited amount of alteration described by Lacroix in the Trenton Limestone in Canada, when in contact with the pegmatitic as compared with the normal nepheline-syenite.

Gen. McMahon said he was glad to add his testimony in corroboration of the conclusion arrived at by the Authors regarding the Sharpley and Peldar-Tor rocks. In 1888 he collected good specimens from both localities, those from Sharpley having been selected

* Pres. Address, 1885, Proc. Geol. Soc. p. 65, &c. vol. xli.

under the guidance of Mr. Hill himself; and a careful examination of thin slices under the microscope had satisfied him that the rocks at both places were true lavas and not altered ashes.

The PRESIDENT remarked that the transference of rocks formerly supposed to be clastic into the massive group was a change that would probably require to be rather extensively made on our maps. There was no doubt that once-fused rocks which had undergone deformation tended to simulate pyroclastic rocks.

Prof. BONNEY had formerly been fettered throughout by the wrong identification of the porphyroids of the Ardennes. He felt the difficulty of coming to a decision, but believed that the bulk of the rock at Bardon Hill was pyroclastic, for it did not resemble a flow-breccia, and appeared to have assumed its present condition before being crushed.

# 10. *On the* Unconformities *between the* Rock-systems underlying *the* Cambrian Quartzite *in* Shropshire. By Dr. Ch. Callaway, M.A., F.G.S. (Read January 7, 1891).

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## I. Introduction.

About twelve years ago I devoted some attention to the Archæan rocks of Shropshire, and a communication on the subject appeared in the Quarterly Journal (1879, vol. xxxv. p. 643). Additional results were published in the numbers for May, 1882 (vol. xxxviii. p. 119), and November, 1886 (vol. xlii. p. 481). Some details, however, remained for settlement. Of these the most important is the relation between the great volcanic system (Uriconian) and the vast series of sediments which takes its name from the Longmynd. Ten years' additional experience amongst the Archæan rocks has given me some advantage in reviewing my old evidence, and recent criticisms * by Prof. Blake call for some notice.

The following is a summary of my published conclusions, with Prof. Blake's objections:—

i. The volcanic rocks (Uriconian) of the Wrekin and Caer Caradoc are older than the Longmyndian. Prof. Blake admits that

* Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 386.

they are older than the upper part of the Longmyndian, but contends that they are not older than the lower part of that series. He accordingly separates the Longmyndian into an upper member (Cambrian) and a lower member (Monian). He furthermore expresses the belief that in one locality (Pontesbury) the felsites regarded by me as pre-Longmyndian are really intrusive in rocks which he considers Cambrian.

ii. The granitic and gneissic rocks (Malvernian) of the Wrekin and other Salopian localities are older than the Uriconian, since they furnish rounded fragments to Uriconian conglomerates. Prof. Blake, on the other hand, holds that the granites are not pre-Uriconian, for in his opinion they are intrusive in the Uriconian, and he maintains that the (alleged) Uriconian conglomerates are of Cambrian age.

In the present paper I uphold my previous conclusions, and offer new evidence in their support.

## II. Review of the Evidence for the respective Ages of the Uriconian and Malvernian Rocks.

In criticising the arguments offered by Prof. Blake, it will not be necessary for me to go into minute detail. If the fundamental positions are shown to be untenable, it would be obviously superfluous to enter upon non-essentials. My proof is presented under the following heads :—

### 1. The Felsites.

Prof. Blake regards the Longmyndian as divisible into two groups : the Upper = Cambrian ; the Lower = Monian. For the purpose of this section, this alleged subdivision is immaterial, and I shall consider the series as one group, the Longmynd Series.

(a) *Church-Stretton Area.*—Prof. Blake arrives at the conclusion * "that the volcanic rocks" (my Uriconian) "are younger than the (Longmynd) slates, and have been extruded from their midst." The evidence brought forward to prove this thesis occupies the two preceding pages of his paper; but after studying these pages very carefully, I cannot find that any distinct proof of intrusion is even alleged. There are certain geognostic difficulties which it is imagined can only be removed by assuming igneous intrusion. Thus, it is alleged that the lower Longmynd slates ("dark shales" of Prof. Blake) show no basal beds, and, therefore, that the volcanic rocks in contact with the slates are probably intrusive. To this I reply :—(1) The junction between the two groups is a fault †, and, therefore, basal beds are not to be expected. (2) The volcanic rocks are mainly volcanic mud, coarse grit, and lava-flows, which must have been formed at the surface, and could not have behaved like a trap-rock.

* Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 407.

† See p. 122.

The only locality in this area where intrusion appears to be affirmed is Helmeth Hill. Here the "boundary of the slate" is said to "zigzag amongst the igneous rocks." I searched this little elevation from end to end, but could not find any slate near any igneous rock, except the ordinary dolerite, which, of course, is unimportant. The summit-ridge is mainly made up of hälleflinta and grit of ordinary Uriconian types, and I have seen no trace of Longmynd slate. The "rhyolite" which, according to Prof. Blake, occupies the southern half of the ridge, is a good quartz and felspar grit!

Prof. Blake appears to have overlooked what I believe to be the only locality in this area where a rock which may be Longmyndian occurs in actual contact with an acidic igneous mass. This section is briefly noticed in a former paper * of mine. The slate or shale, which forms a very thin band, dips in a westerly direction in conformity with the apparently overlying Uriconian grits and argillites. At its northern end it is surrounded by dolerite and has undergone alteration, while its cracks are injected with red felspar. A few yards farther south, the slate is immediately succeeded by a band of felsite, which is overlain by dolerite. The felsite is of a brick-red hue, and closely resembles a felsite which in Charlton Hill forms a dyke, cutting across the strike of the Uriconian. A slide from each locality has been microscopically examined. Prof. Bonney, who favoured me with his assistance in my earlier work in Shropshire, has kindly looked through the slides prepared for this paper, and given me his opinion on critical points. The slide from the Charlton-Hill dyke he describes as a "quartz-felsite, showing some approach to a micrographophyric structure." The other has a "somewhat similar structure, but less strongly marked." He agrees with me that these felsites are "rather different from the ordinary Wrekin lavas." It is probable, therefore, that the Ragleth felsite, like the mass at Charlton Hill, is an intrusive dyke. A fault, shown on the Survey Map, passes along the base of the Ragleth where the slate, felsite, and dolerite appear, and it is possible that the slate is a faulted fragment of the Longmyndian.

(b) *Pontesford-Hill Area.*—This is the only locality where it is definitely asserted that contact-alteration has been produced by rhyolite alleged by me to be Uriconian. At the bottom of p. 402 †, it is stated that "the slates and grits which here alternate above the falls are very much altered as they approach the igneous rock, the grit being rendered micaceous and the slate chiastolized, and both are indurated." The two formations, Longmyndian and Uriconian, are clearly exposed in a stream-section, and the exact spot of the supposed metamorphism is fixed by the words "above the falls." No signs of alteration are, however, seen on the ground, nor can the grit and the shaly rock be distinguished in hand-specimens from typical Longmyndian. Two specimens were selected for the microscope as being rather more shaly than usual, and

* Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 659.

† *Ibid.* vol. xlvi. (1890).

therefore more susceptible of alteration, No. 543 * being within one yard from the Uriconian, and No. 544 about six yards distant. The former is a mudstone, the latter a grit; and the materials of both are largely volcanic. Neither Prof. Bonney nor myself could detect any signs of alteration or any traces of chiastolite. Indeed, Prof. Blake himself has omitted to give us any microscopic evidence on these points, though it is obvious that they are of critical importance.

As this crucial case breaks down on examination, I thought it needless to re-examine the other masses of Uriconian which appear on the line of the great Pontesford-Linley fault.

## 2. The Alleged Unconformities.

Roughly speaking, the Longmynd rocks may be divided into an upper member, coloured purple, and a lower member, coloured green; though purple rocks occur in the lower part, and green rocks are occasionally found in the upper. By Sir R. Murchison and the Geological Survey the two members were united into an unbroken series, and this view has been generally accepted. In Haughmond Hill there is a marked break between the purple and the green beds, as I pointed out to Prof. Blake; but it can be demonstrated that this is due to faulting, and, from a general acquaintance with the Longmyndian rocks, I have not been led to question the received opinion.

Prof. Blake is the first to dissent from the old view. He considers that the Longmynd Series is divisible into two groups separated by a marked unconformity. The upper member he correlates with some part of the Cambrian, the lower he places in his so-called "Monian" system.

I contend, however, that Prof. Blake has not proved his case, and that, if he had done so, he would hardly have refuted my evidence from included fragments, since well-rounded pebbles of volcanic rock are found in the lower series as well as in the so-called "Cambrian."

(a) *The supposed Break in the Longmyndian.*—The general section † offered by Prof. Blake appears on the face of it improbable. He draws the upper series as dipping at about the same angle and in the same direction as his so-called "Monian"; but, just at the contact, the basement beds of the "Cambrian" are represented as creeping up over the edges of the "Monian," and lying to the east of the junction in outliers, horizontal "Cambrian" resting on nearly vertical "Monian." So extraordinary a section surely requires some explanation.

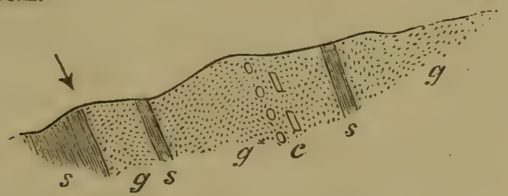
In pursuance of my plan, I have carefully examined one of Prof. Blake's critical sections, the "outlier" at Narnell's Rock. The actual junction is figured by Prof. Blake on page 395 ‡, and the

* So numbered in my cabinet.
† Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 392.
‡ *Op. cit.*

grit ("Cambrian") is shown as squeezed into the slates ("Monian") so as to be nearly conformable. There is in truth no unconformity whatsoever. The slate, it is true, is somewhat abruptly succeeded by the grit, which is very massive and shows little clear bedding; but a conformable passage between the two is apparent without any very critical observation. The reading of the section is represented in fig. 1, below, and my note-book supplies the following particulars:—

Approaching the section from the east, we pass alternations of purple slates and grits. At Prof. Blake's "junction," we have, on the east side, purple slaty beds interlaminated with seams of purple grit, both slates and grits being rather micaceous. On the west side is a bed of the grit, which appears to have been a little squeezed into the slate, so that here and there a trivial unconformity between

Fig. 1.—*Section at Narnell's Rock.*




↘. Junction of Prof. Blake's "Monian" with his "Cambrian."
*c.* Conglomerate, with flakes of shale.
*s.* Shaly and slaty beds.
*g.* Grit.

the two beds is apparent. A seam of slaty rock overlies the first grit-band. A few yards farther on is a thin bed of conglomerate. The included pebbles are largely of quartz, but there also occur numerous thin flakes of purple shale, and these lie flat in the plane of the seam. A little farther west there appears a band of thin-bedded grit, with abundant mica on the lamination-surfaces. These three beds—slate, conglomerate, and laminated grit—have the same dip (N.W. by W. at a high angle) as the underlying "Monian." The alleged unconformity is thus absolutely disproved, so far as this section is concerned.

All the grit in the crags to the west is apparently massive, and as there are no exposures in the slopes below the section, there is an appearance of what Prof. Blake calls a "horizontal crag." That this grit is not an outlier, but an integral part of a regular series, is further evident from the fact that it can be followed on the strike into Callow Hollow on the south, and into Lightspout Hollow on the north, to say nothing of more distant localities.

It seems to have been supposed * that the flakes of purple shale found in the upper series are derived fragments from an earlier formation. This argument, if it were taken into consideration,

* *Op. cit.* pp. 392, 393.

would prove too much; for I have found similar flakes low down in the great grits of the so-called "Monian" on the southern slopes of the Ashes Hollow. I need hardly state that they are devoid of significance.

In pointing out the insufficiency of the above attempt to refute the received views, I do not wish to prejudge issues outside the present enquiry. I have not critically studied the whole of the Longmynd area, and must leave some points for future research.

(b) *Presence of Rolled Fragments of Volcanic Rock in the so-called "Monian" Series.*—These are not very common; but they exist. One good specimen I found in the green grit of Ashes Hollow. It is a well-rounded pebble of about one inch in diameter. The material is certainly volcanic. In the field it looked like felsite, and under the microscope it appeared to me to show a micro-crystalline structure. Prof. Bonney leans to the opinion that it is allied to obsidian, though he does not absolutely exclude the alternative of a highly altered mudstone. As there are no lava-flows in the Longmynd Series, and, so far as I know, no mudstones resembling felsite, it would seem that such pebbles must be derived from an earlier formation.

### 3. The Conglomerates and Grits.

Prof. Blake truly remarks (*op. cit.* p. 408) that the age of these conglomerates and grits is "of supreme importance in connection with the general interpretation of the district." With equal accuracy, he adds that they have been taken by the present writer to be "part of the volcanic series." He is not, however, correct in saying that I regard them as proving "the clastic origin of the latter." It is true that a grit contains the evidence of its own "clastic origin"; but it certainly does not carry with it the genesis of any lava-flows that may be associated with it.

Prof. Blake contends that these clastic rocks do not belong to the Uriconian, but are outlying patches of the "Cambrian" strata which form the western half of the Longmynd Series. He mentions examples occurring on the Cardington *massif*, on Caer Caradoc, and on Charlton Hill. I will deal with these *seriatim*.

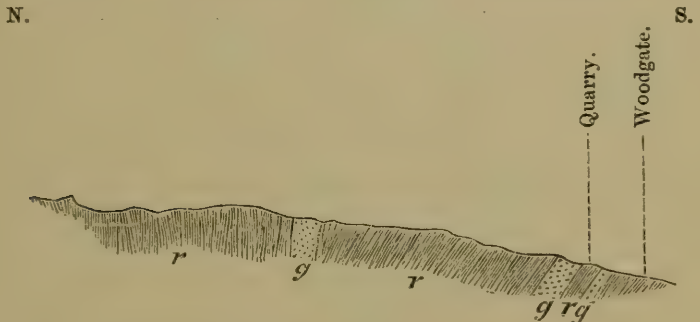
(a) *The Cardington* Massif.—Certain patches of grit at or near the Gaer Stone are said to be "superficial," but no evidence is offered in support of that opinion. One of the numerous patches that lie near Willstone Hill is noticed; but again its "Cambrian" age is assumed. I have examined a large number of exposures of grit in the western part of the Cardington mass, but could obtain no evidence of unconformity. Farther east, however, there is clear proof in at least two localities that this grit is intercalated in the volcanic series. One mass occurs a little more than half a mile east of the Gaer Stone in the ravine which opens on to the Hope-Bowdler road, opposite "The Yells." This rock is of the usual type, as described by Prof. Bonney in an appendix to my 1879 paper *,

* Quart. Journ. Geol. Soc. vol. xxxv. p. 607.

consisting mainly of quartz and red felspar. It varies in the degree of coarseness between microscopic grains and bits of $\frac{1}{8}$ inch in diameter, and this character gives us the means of determining the strike. At two spots on the western side of the glen, a clear strike may be made out by following the coarse seams. In one case the direction is E. and W., in the other N.W. by W. The dip is vertical or very high. At the southern end of the section the grit is almost black, and this peculiar variety crops out on the opposite slope about 50 yards to E. by a little S. The strikes agree therefore in a general way with the usual strikes of the volcanic rocks in the Cardington mass. See the accompanying map, facing p. 120.

The other locality is in the quarries at Woodgate, where is exposed the clear series of rhyolites and grits described in my 1879 paper (*op. cit.* p. 658). These rocks are admitted by Prof. Blake to belong to the true volcanic group. I have recently detected at the back of this quarry, at the western extremity, and almost on the strike of the green grits, a reddish grit, composed of quartz and red felspar, with some bits of rhyolite. In hand-specimens it is seen to be quite of the ordinary Uriconian type. The annexed section (fig. 2) shows the relation of the grits of these two localities to the associated volcanic rocks.

Fig. 2.—*Section across the Hope-Bowdler mass.*




*g*. Grit. *r*. Rhyolite.

(b) *Caer Caradoc.*—The mass of grit near the south-western end of the ridge is regarded by Prof. Blake as a mere surface-patch. There is, however, very clear proof that it is intercalated in the Uriconian. In one place it is distinctly bedded. The reddish variety alternates in regular seams with a dark grit, with a shaly band, and with a fine-grained compact rock, like hälleflinta, but whether igneous or aqueous is uncertain. Prof. Bonney inclines to the former belief.

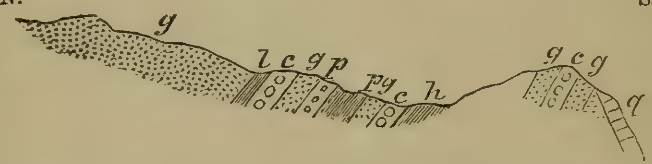
These beds dip very clearly to the N.E. Both above and below numerous exposures of the ordinary hälleflinta of the district are seen to crop out, with the same dip, or, where the dip is not apparent, with a strike to N.W. or N.N.W.

(c) *Charlton Hill.*—Clearer evidence for the pre-Cambrian age of the grits and conglomerates could hardly be desired *. After Prof.

* Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 653; vol. xlii. (1886) p. 483.

Blake's communication was read, I went several times over the ground and examined the critical sections foot by foot. Weathering and cart-wheels had exposed new outcrops, and the evidence I obtained strongly confirmed my published conclusions. The annexed section (fig. 3) illustrates the main points. I will take the section from N. to S.

Fig. 3.—*Section across Charlton Hill.*




| | |
|---|---|
| *c*. Conglomerate. | *l*. Andesitic lava. |
| *g*. Grit. | *h*. Hälleflinta. |
| *p*. Pebbly grit. | *q*. Cambrian quartzite. |
| *pg*. Grit and pebbly grit. | |

The volcanic grits forming the northern part of the hill do not show any clear dip. The first rock that attracts attention, as we keep along the western side, is an andesitic lava, showing a flow-structure, which under the microscope becomes very distinct. The strike is about E. and W., and the dip nearly vertical. We next come to the well-known conglomerate on the top of the hill. It displays no clear dip or strike, but the majority of the pebbles have their longer axes trending N.W. by W. A few yards south of the strike of this conglomerate, in the surface of the road, a very instructive section has been exposed. Grit-bands alternate with finer compact material. One of the grits is of the ordinary Wrekin type, the fragments being chiefly felsite. Separated from this by a compact seam is a coarser grit of which the fragments are mainly quartz, red felspar, and red granite, some of the larger pieces being well rounded. Small pebbles of mica-schist also occur in this band. Thus, within 2 feet in the same solid mass, we have one bed which is distinctly Uriconian, and another of the type which Prof. Blake would probably call "Cambrian." The strike of these beds is clearly N.W. by W., and therefore parallel to the conglomerate.

We next come to the well-known section seen in the northern bank of the hollow road to the S.E. of the last spot. Prof. Blake's drawing * shows a mass of structureless hälleflinta with the surface hollowed into two depressions in which lie small synclines of "Cambrian grit." He says that the grit, in two masses, dips "in certain parts towards the W., but becomes almost horizontal through disturbance." At only one spot could I find a westerly dip; but the rock was dolerite, and the sloping slabs are produced by joint-planes. Nor could I detect horizontal bedding; but, since the strike of the beds is nearly parallel to the section, the outcrops, viewed from a distance, appear nearly horizontal. Caution is therefore necessary in working out the stratification. As we descend the

* Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 409.

road, and examine the re-entering angles in the vertical rock-surface, we can make out the true dip, bed after bed, and measure a thickness of from 20 to 30 feet. The upper strata are strictly typical of the volcanic series, as it is exposed in Lawrence-Hill Quarry, at the foot of the Wrekin. Associated with these grits and hornstones are bands which are even more distinctly sedimentary, consisting of a sort of claystone, with thin seams of small pebbles composed of materials substantially identical with the included fragments of the main conglomerate. At a recent visit, I was accompanied by my friend Dr. Geo. Deane, F.G.S., who, with compass and clinometer, ascertained that these beds dipped to the north at 70°–75°, a result which differs very slightly from my observation already recorded in the Quarterly Journal *.

At nearly the bottom of the section, just before we reach the Cambrian quartzite, we come to another conglomerate, with large well-rounded pebbles of quartz, quartzite, granite, and various schists. In hand-specimens, the matrix looks like a slightly porphyritic felsite. Prof. Bonney finds this matrix very difficult of determination; but he is disposed to regard most of it as clastic volcanic material. I confess I am not quite satisfied with this opinion, but the point is not very important.

Further proof of the Uriconian age of the conglomerate is found in the small elevation to the S. of Charlton Hill. Typical Uriconian ashes and grits, with an E. and W. strike, are exposed on the plateau. Towards its southern margin, forming a small crag, there is an outcrop of the ash containing an irregular band of conglomerate, 8 or 9 feet from E. to W., by 3 or 4 feet in breadth. Some of the pebbles are of unusual size, reaching a diameter of 5 or 6 inches. Hand-specimens are procurable, in which one or more rounded fragments of granite and other rocks are embedded in as typical an ash as any that can be found in the Wrekin area.

I may add that in the Lawrence-Hill Quarry, and on the Wrekin itself, grits and conglomerates occur which differ only from those just described in the larger proportion of felsite-fragments. South of the Wrekin and Wrockwardine masses, the signs of purely volcanic action decrease. They are less conspicuous even at Charlton Hill; but, in the Church-Stretton area, rhyolites are much less prominent and felsite fragments decrease in number, while distinctively sedimentary material increases in proportion.

It is almost superfluous to point out that the proof of the Uriconian age of the conglomerates involves the pre-Uriconian age of the granite and metamorphic land-masses from which so many of the fragments were derived. Some of the granite-fragments, as Prof. Bonney and myself have shown †, are similar to the rock which occurs at the two opposite ends of the Wrekin chain. This statement has an obvious bearing upon Prof. Blake's opinion that the granite of the Wrekin is intrusive in the volcanic series.

* Vol. xlii. (1886) p. 483.

† Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 654; vol. xlii. (1886) pp. 483–485.

### 4. The Granitic Rocks.

Prof. Blake appears to have discovered some new outcrops of the granite. He says "there are two small patches of it in the midst of the rhyolites near the south-eastern end of the Wrekin." But, as the Wrekin is a narrow ridge trending N.E. and S.W., it cannot have a "south-eastern end," and we are therefore left in the dark as to the situation of the new masses. Wherever they are, they must be very small.

At Primrose Hill, the granite is thought by Prof. Blake to "suggest a neck." He states that it "almost seems to pass into rhyolite." I can find, however, no rhyolite near the granite. The rock into which the granite really passes is fine-grained and compact; but, under the microscope, it is seen to be merely a crushed state of the granite, as first suggested to me by Prof. Bonney. A series of microscopic slides shows the actual stages of the crushing process.

There remains the difficult and obscure section at Ercal Hill. Very little is to be learned in the field. At one spot I once saw a mass of felsite included in the granite; but all the rock was too much decomposed for satisfactory study. On the other hand, I have never found a vein of the granite in the felsite. The junction is nearly a straight line, and is marked by some minute crushing. There is some reason to suspect a fault.

Since writing the above, I have received a note on the subject by Prof. Bonney. He has examined a new junction-specimen of mine, and re-examined several slides of his own. He says, "Certainly there is nothing to show that the granite is intrusive in the felsite," and he thinks there are signs of fault-brecciation. He cannot find any distinct proof of the intrusion of the felsite in the granite. We may then fairly conclude that Prof. Blake's opinion receives no support from the study of the rocks, either in the field or under the microscope, and the evidence from included fragments, given in the last section, may be allowed its due weight.

The pebbles of granite and schist in the Charlton-Hill conglomerates clearly prove the unconformity between the Uriconian and an earlier rock-system. The nature of the break between the Uriconian and the Longmyndian will be more fully explained in Part III.

## III. The Relation between the Uriconian and the Longmyndian.

The age of the Longmynd rocks must be considered as *sub judice.* The antique facies of the fauna of the Hollybush Sandstone and the gap between that formation and the Upper Cambrian led me many years ago to doubt the Upper-Cambrian age of the former, and I have provisionally regarded it as Menevian. The obvious hiatus between the quartzite underlying this sandstone and the Longmynd Series rendered the Cambrian age of the latter highly improbable,

and I thought it convenient in 1887 * to give to this great group the local designation of "Longmyndian." Prof. Lapworth has since announced the discovery of fossil evidence for the Lower-Cambrian age of the Hollybush Sandstone; but, pending the publication of his details, it would hardly be wise to positively assign a pre-Cambrian age to the Longmyndian system.

Our present object is to ascertain if there is a time-break between the Uriconian and Longmyndian, and, if so, whether it is a small or a great one.

That there is a break will, I think, appear from the following considerations.

### 1. The Discordance of Strike between the two Groups.

It is well known that the normal strike of the Longmynd rocks is N.N.E. I have made observations in hundreds of localities, from Haughmond Hill on the north to a newly discovered inlier on the borders of Herefordshire on the south; and I have found that, though there are occasionally slight deviations and abrupt twists, the normal strike, even in faulted masses, is maintained with remarkable uniformity. The strikes in the map which faces the next page have all been personally verified.

On the other hand, as I pointed out in 1879, the normal strike of the Uriconian is more or less transverse to the above. In a volcanic series, we should not expect the strikes to be uniformly parallel or persistent for great distances; nevertheless, it will be found that the exceptions to the above rule are not very numerous. I have recently reviewed the original evidence with great care, and have discovered new strikes in all the chief masses. The enlarged evidence is summarized in the map, which represents the minimum number of strikes observed, but where several occurred in the same vicinity only one is usually drawn. I have been careful to supply nothing from the imagination. Even when a curve in the strike appeared to be fairly deducible from several disjointed exposures, I have not connected the broken lines, unless they were so near together that it would be mere pedantry to refuse to join them. I will now take the chief areas in order.

(a) *Lilleshall Hill.*—Strikes are clearly seen almost from end to end of the ridge. Some of them are in rhyolite, others in slaty ash-beds. They vary between E. and W., and N.E. by E.

(b) *The Wrekin Chain.*—A strike, originally mapped as occurring in the so-called "granitoidite" of the Ercal, must be erased. The rock is now regarded as a true granite, and its band of fragments is probably a crush-breccia. The transversal strikes in the rhyolite at the southern end of the Ercal, as also those in the hornstones, ashes, and agglomerates of Lawrence Hill and the northern end of the Wrekin, are confirmed. I have moreover made out a number of new strikes in rhyolite along the N.W. side of the Wrekin nearly as far south as the summit, and I find that most of them trend E.N.E.;

* Trans. Shropsh. Archæol. Soc. for 1887.

that is, parallel to the overlying grits. The strikes in the Wrekin thus agree with those of Lilleshall Hill.

(c) *The Wrockwardine Mass.*—The rock is mainly rhyolite. There is great variation in the strikes, and they are frequently curved, as we should expect. There is, however, a predominance of what we may call "Longmyndian strikes," such as N. and S., or N.N.E. and S.S.W. Lava-flows are of course less reliable as indications than clastic beds. At the edge of the area, near Leaton, is a small section of hornstone and volcanic grit, with a high westerly dip. This is the only case in the Wrekin area, so far as I know, in which clastic rocks have a Longmyndian strike.

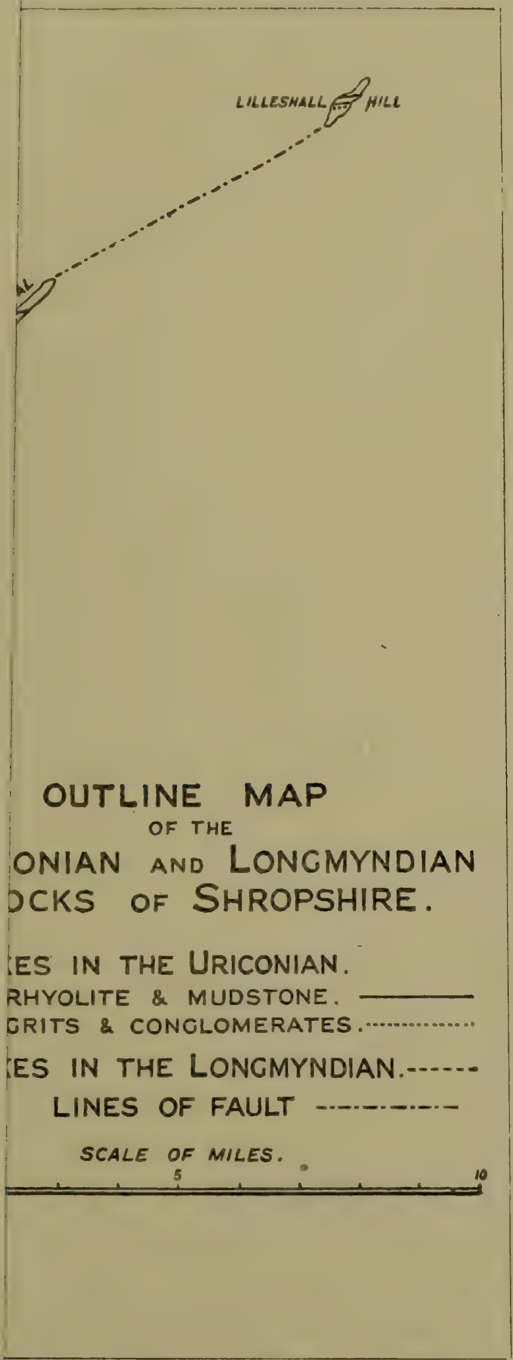
(d) *Charlton Hill.*—The numerous clear strikes visible in this area are all, with one exception, in clastic beds. The andesitic lava, the conglomerates, grits, hornstones, and argillites have a steady dip to the north, or a little east of north. The strike in the lava as well as several very distinct strikes in grit and conglomerate have been recently discovered, and they agree with my old results.

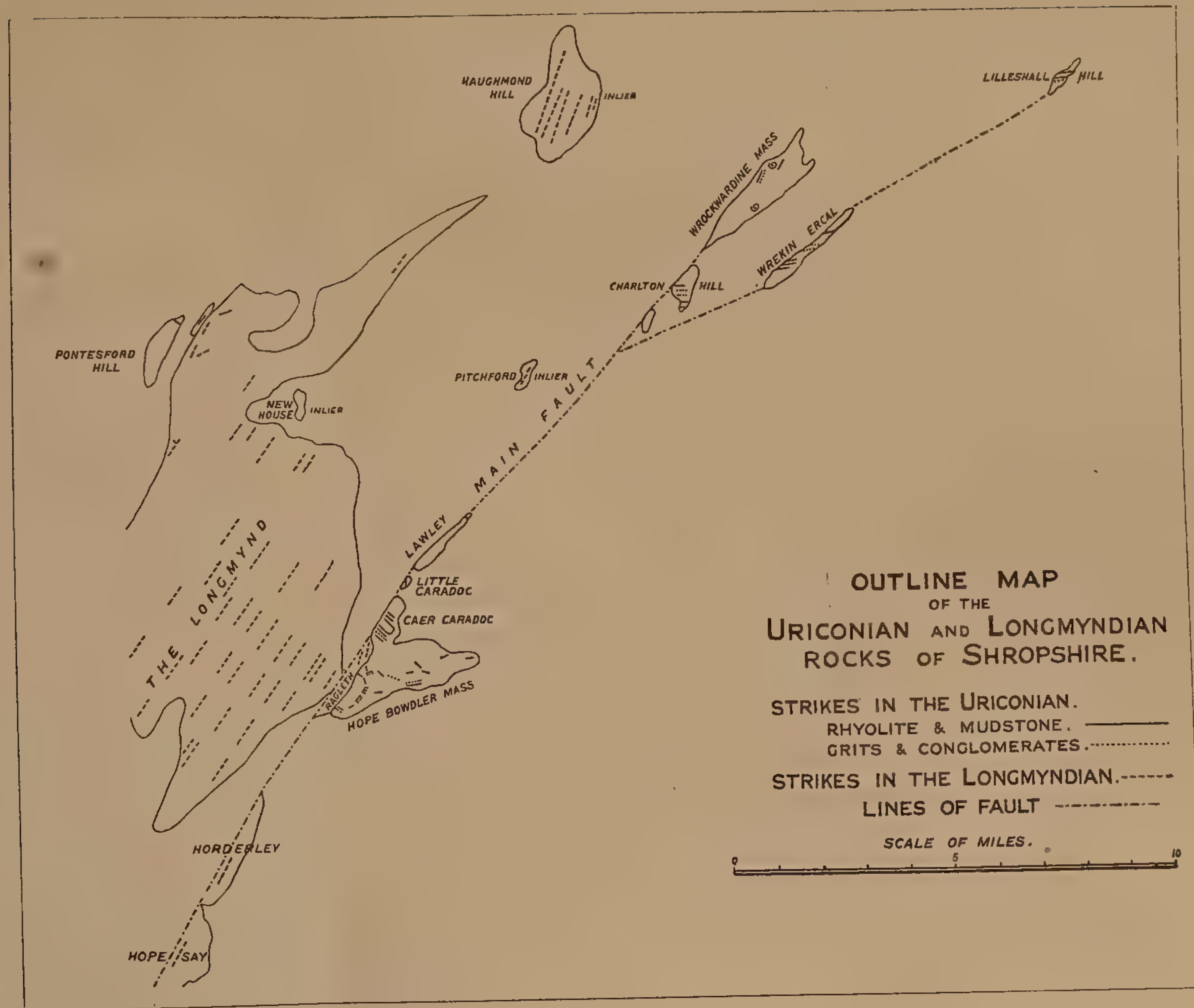
(e) *The Lawley.*—I have found here but one exposure of sedimentary rock with a distinct strike, and that is about E. and W.

Prof. Blake remarks that some of the rhyolitic-looking rocks in the Church-Stretton district, when microscopically examined, turn out to be slates. I can confirm this statement, though I would rather describe some of these fine-grained compact rocks as argillite, or even hornstone. In the field it is sometimes impossible to distinguish between a sedimentary deposit and a true lava-flow. Prof. Bonney has examined for me several varieties of compact rock from Caer Caradoc and the hills to the south. He identifies the majority of them as a sort of volcanic mud, one or two as probably igneous, and one or two as doubtful. True lava-flows occur in the middle of Caer Caradoc, in the Hope-Bowdler district, and perhaps elsewhere; but recent investigations demonstrate that sedimentary material forms a larger proportion of the Uriconian rocks of the Church-Stretton area than we had supposed. This will make the strikes of the region more reliable for our present purpose. Where I have not been able to identify a hard, compact, flinty rock as either igneous or sedimentary, I have found it convenient to employ the vague and, I think, useful term "hälleflinta." The strikes in these rocks are usually indicated by a coloured banding or by a platy structure.

(f) *Caer Caradoc.*—The strikes are numerous and clear. Many of them are in hälleflinta, some are in rhyolite, and at the S.W. end there are very good strikes in grit and shaly mudstone. It will be seen from the map that the prevailing strikes are almost at a right angle to the strike of the Longmyndian, which here comes close up to the Uriconian; so that on the western side of the hill the discordance of strike may be seen within a couple of hundred yards, the green Longmyndian slates striking N.N.E., while the beds of hälleflinta and grit on the slopes above trend to the N.W. Some of the Uriconian strikes are seen to form curves, and one of them comes out very clearly. A band of hälleflinta strikes across the ridge in a south-easterly direction, then it bends round to the E., then turns

[*To face* p. 120.


LILLESHALL HILL
OUTLINE MAP
OF THE
ONIAN AND LONGMYNDIAN
OCKS OF SHROPSHIRE.
ES IN THE URICONIAN.
RHYOLITE & MUDSTONE.
GRITS & CONGLOMERATES.
ES IN THE LONGMYNDIAN.
LINES OF FAULT
SCALE OF MILES.
5
10


HAUGHMOND HILL
INLIER
LILLESHALL HILL
WROCKWARDINE MASS
WREKIN
ERCAL
CHARLTON HILL
PONTESFORD HILL
PITCHFORD INLIER
NEW HOUSE INLIER
MAIN FAULT
LAWLEY
LITTLE CARADOC
CAER CARADOC
THE LONGMYND
RAGLETH
HOPE BOWDLER MASS
HORDERLEY
HOPE SAY
OUTLINE MAP
OF THE
URICONIAN AND LONGMYNDIAN
ROCKS OF SHROPSHIRE.
STRIKES IN THE URICONIAN.
RHYOLITE & MUDSTONE.
GRITS & CONGLOMERATES.
STRIKES IN THE LONGMYNDIAN.
LINES OF FAULT
SCALE OF MILES.
0
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and keeps to the N. for some distance; finally it curves abruptly, and runs straight to the N.W., nearly (or quite) reaching the fault. Thus is formed an oblique parallelogram, whose north-western side is wanting and whose eastern angles are rounded off. All the dips slope inward, and the centre of the figure is occupied largely by dolerite. South of this figure the dips are to the N.E. and N. of it; while in the centre of the hill the dips are very variable.

(g) *Helmeth Hill.*—There are no good exposures, except along the summit-ridge, which is mostly occupied by grit and hälleflinta. A red band in hälleflinta displays a north-westerly strike, but I do not like to rely upon it and have not inserted it in the map.

(h) *Hazler Hill.*—At the northern end, a banded argillite strikes N. and S. This Longmyndian strike occurs within 70 yards of the true Longmynd slate with the normal trend. On the eastern side of the hill, a small quarry exposes a good section of volcanic beds, dipping to the N.W. In ascending order, the strata are purple fine-grained ash, pale green porcellanite, coarse grey ash, and fine-grained grey ash. The beds are very irregular, and thin out like wedges. This is one of the most Pebidian-like sections that I have seen in Shropshire.

(i) *Ragleth Hill.*—The rocks forming the mass of this hill are very sedimentary, consisting mainly of argillite and grit, with some hälleflinta. I have not found in it any igneous rock except intrusives. At both the north and south ends the strikes are about N.W. by W., but in both cases the beds at their eastern ends curve round and keep along the eastern side of the ridge with a N.N.E. strike. We have thus another figure similar to the imperfect parallelogram in Caer Caradoc, the north-western side, as in that case, being absent, and the dips being inward.

(k) *The Cardington and Hope-Bowdler Mass.*—The materials of this group of hills are like those of Caer Caradoc, with certain differences. Coarse grits are abundant towards the N.W. part; felspar-porphyry and rhyolite predominate towards the S. and S.W. Strikes are recorded on the map from nine principal localities. Near the Gaer Stone, one strike is E. and W., another is to the N.W. North-east of Hope Bowdler a conspicuous band of felspar-porphyry trends east and west. Just at the back of the village this rock is well exposed in a farm-road, and the strike is quite clear, bands with numerous porphyritic crystals alternating with more compact seams. The strikes in grit in the ravine opposite "The Yells" and in Woodgate Quarry have been already noticed. In the glen above Woodgate, a thick band of rhyolite strikes parallel to the grits (E. and W.), and the lavas and ashes in the quarry run in the same direction. South-west of "Middle-Hill" Farm, hälleflintas at several spots have a strike to W.N.W., in others to N.W. Towards the eastern end of the *massif*, at Stone Acton, there have been noted in hälleflinta one strike to E.N.E. and one with an E. and W. trend.

Some of these strikes are, for volcanic rocks, of considerable length. Thus, the green grit of Woodgate Quarry reappears on the

strike to the east at a distance of nearly a quarter of a mile. Also the felspar-porphyry of Hope Bowdler runs E. and W. for about half a mile.

Besides calling attention to the occurrence of structural strikes, it is of importance to point out the trend of large masses. Thus, the rhyolite in the Woodgate glen appears to strike almost E. and W. across the two ravines to the west, and to be produced less distinctly in the opposite direction to Stone Acton, so that it is probably continuous from end to end of the Cardington *massif*. Also the strike of the grit in the glen opposite "The Yells" is in a line connecting masses of grit at Gaer Stone with others in the Woodgate ravine, and this line is parallel to the strike of the adjacent rhyolite. On the other hand, I have not observed that any bedded or banded rock in this district trends in a direction transverse to the prevailing strikes.

Summarizing the details of all the districts, we notice that the strikes in the Wrekin area are usually either E. and W. or E.N.E. and W.S.W.; in the southern area, they are E. and W. or some point between W. and N.W. The only strikes in the Uriconian which lie parallel to the normal Longmyndian strike are those near Wrockwardine, at the northern end of Hazler Hill, and on Little Caradoc and the last-named is really a little to the west of north. The bands in Caer Caradoc and Ragleth which trend to the north can hardly be reckoned, for they curve round at each end, and abut on the fault at nearly a right angle to the Longmyndian strike. It will be observed that all the Longmyndian strikes in Uriconian rocks are near the fault. Also that, in such important masses as Charlton Hill and Caer Caradoc, the transverse Uriconian strike comes close up to the fault. It is hardly rash to assume that the strikes at a distance from the great fault are least likely to have been disturbed, and are therefore most reliable as indications of the original lie of the rocks.

## 2. The Faulted Junction.

The two formations come into visible contact along a line of only about $2\frac{1}{2}$ miles. The fault drawn on the Survey map runs in a straight line from the western margin of Caer Caradoc to Little Stretton, throwing down Silurian (Wenlock) rocks against Ordovician and older systems. The area east of the fault is marked "b [3]" (Caradoc) on the map, but it is correctly recognized by Prof. Blake as Longmyndian. It is this mass which abuts upon the volcanic series. The contact is certainly a fault at the northern end, near Caradoc Coppice. The dislocation can be taken up again about a mile to the south, near the cluster of cottages called Hazler. An interesting section of the junction-rocks is seen on the old road up from Church Stretton to this locality. The ordinary green slates of the Longmyndian crop out at intervals up the road for nearly half a mile, with the normal strike to N.N.E. As we approach the hamlet, the slate loses its lamination, and, near a well, it comes to an abrupt end. At this point it has a burnt appearance,

and the cracks are injected with red felspar. No igneous rocks are seen near, but the alteration-effects just described are similar to those observed at the contact of slate with dolerite east of Ragleth Hill (p. 111). About 70 yards farther on, we come to slaty and gritty rocks of a Uriconian appearance, which obviously could not have produced the alteration. The most probable explanation of the facts is a fault, with an intrusion of the dolerite which occurs in force on the same line of fault farther south. There is very little discordance of strike between the two systems at this locality.

This fault does not, of course, prove an unconformity; but it helps to invalidate the hypothesis of conformity.

### 3. Differences in the Conditions of Deposit.

The Uriconian is essentially a volcanic formation. In the Wrekin area, the rhyolites and felsite-grits form the chief mass; beds with rounded fragments being very inconspicuous. In the Church-Stretton district, sedimentary matter, chiefly in the form of volcanic mud, is more prominent. But, throughout the Uriconian area, the comparative rarity of clear stratification is a marked feature. The ashes and hornstone of Lawrence-Hill Quarry, taken as the typical Uriconian section, were described by Sir R. Murchison and the Survey as intrusive "greenstone." Even the clear sedimentation of Charlton Hill was overlooked, and the mass appears on the map as "greenstone." Large parts of the Wrekin have been subjected to close and repeated examinations without yielding any evidence of bedding. The conglomerates of the Wrekin area can hardly be called beds at all; they are mere irregular patches, somewhat elongated in the direction of the strike of the ash-beds with which they are associated, and in a greater or less degree they shade off into the finer materials.

In the Uriconian hills of Church Stretton, although I have observed grits in thirty or forty different localities, in only four or five of them has a strike been detected, and in only two of these cases could it be proved to extend for many yards. The strikes are more persistent in the hälleflinta, but a glance at the map reveals how rarely they can be followed for great distances. The irregularity in the shape of the masses of grit in this area is a marked feature. One example will serve as a type. It occurs at Hazler, and forms part of the Uriconian rock lying east of the fault (p. 122). When I first approached this spot, I saw what looked like a granitic rock intruding into slates. The seeming granite was without trace of bedding or lamination. It cropped up in the road in irregular masses amidst laminated slaty rocks; on the northern bank it rose up into the slate in a somewhat dome-like form, and on the southern side it also appeared irregularly. A slight examination with a lens dispelled the illusion, and proved that the rock was a quartz-felspar grit. These irregular lumps of grit are explicable only as the result of direct volcanic action.

Contrast the irregular arrangement of the volcanic ejectamenta of

the Uriconian area with the even sedimentation of the Longmynd Series. The uniformity of the strikes and the regularity of the bedding in the latter are too well known to need comment. Even conglomerates, which hardly form beds at all in the volcanic series, can be traced on the strike mile after mile almost from end to end of the Longmynd chain. This change from almost pure vulcanism to pure sedimentation must surely indicate a break in time.

The unconformity between the Uriconian and the Longmyndian is not necessarily a very great one. In so early a period of the earth's history, when the crust was more easily bent and broken, and in a region of energetic vulcanism, new axes of upheaval might be formed with comparative rapidity. Then, too, it must be admitted that the grits and slates of the Longmyndian do not materially * differ in their composition from the grits and mudstones of the older series. Nevertheless, the unconformity appears to be real, and I submit that the terms "Uriconian" and "Longmyndian" are worthy of a place in our nomenclature.

## Discussion.

Prof. Blake had not regarded the volcanic rocks as *intrusive*, but as having burst out from amongst the slates. Any evidence derivable from Lyd's Hole he had shown to be immaterial. The main point in his (the speaker's) paper was the subdivision of the Longmynd rocks into two great groups by an unconformable overlap betwixt the Upper and Lower groups—the similarity of strike being due to subsequent pressure. No satisfactory conclusion could be derived from the examination of a single section such as that at Narnell's Rock; but his assertion of an unconformable overlap had been arrived at after tracing the junction across the district. He had seen fragments in the Lower group like the specimen exhibited, and admitted that they were puzzling, as he had mentioned in his paper. It was not of primary importance whether the conglomerates on Charlton Hill were superficial or not, for he regarded the whole as lying at the very base of the Cambrian. He had no doubt that there was plenty of crushed granite amongst the rocks on Primrose Hill. He was not much concerned in the relations of the Ercal-Hill Red Rock, but would like to know where the rhyolite was entirely surrounded by it. He would ask, if the whole of the Longmynd rocks were to be called Longmyndian, where was the Cambrian of the western part of the district?

Prof. Bonney had seen the Charlton-Hill section, and thought that the evidence was in favour of Dr. Callaway's views, and he might say the same of the Ercal-Hill section. The so-called "chiastolite rock" had been examined by him without finding any sign or probability of the existence of chiastolite.

Dr. Hicks, so far as his examination of the district had gone, was inclined to follow the Author rather than Prof. Blake. He main-

* The chief difference is that mica is abundant in the newer series and rare in the older.

tained that the source of supply of the Longmynd Series was the Caer Caradoc volcanic group. There was no indication of a volcanic group in the Longmynd rocks, and it was much more likely that the volcanic rocks existed previously to their deposition. He as yet saw no reason for separating the Longmynd Series from the Cambrians.

The AUTHOR had difficulty in understanding Prof. Blake's theory of *extrusion* as distinguished from *intrusion*. The rocks at Lyd's Hole were important, because it was the only locality where Prof. Blake affirmed the existence of contact-alterations. With regard to the apparent conformity produced by squeezing, he would ask why the outliers were not also conformable. He could not follow Prof. Blake's arguments concerning the conglomerates on Charlton Hill; because the outcrops were circumscribed, it did not follow that the patches were Cambrian, and, as a matter of fact, the rocks have a dip and strike conformable with that of the associated rhyolites. The Cambrian occurs on the west side of the Longmynd, under the Stiper Stones; for the Shineton shales are seen there, and there is also a fault, cutting out the Lower-Cambrian rocks.

## 11. *On the* Age, Formation, *and* Successive Drift-Stages *of the* Valley *of the* Darent; *with* Remarks *on the* Palæolithic Implements *of the* District, *and on the* Origin *of its* Chalk Escarpment. By Joseph Prestwich, D.C.L., F.R.S., F.G.S., &c. (Read January 21, 1891.)

[Plates VI., VII., & VIII.]

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### § 1. General Character and Age of the Darent Valley *.

In former papers † I have touched incidentally upon the drift phenomena of this district, and on the occurrence of a peculiar group of flint implements found on the adjacent Chalk plateau. I now purpose to limit my observations to the circumscribed valley of the Darent, which I have had more special opportunities of studying since my residence at Shoreham.

This valley, including the district surrounding it, is of peculiar interest, from the circumstance that its geological history, beginning with pre-Glacial times, may, with few breaks, be traced to Neolithic times; as also from the light it throws upon the age of some of the Thames-Valley drifts, and from its distinctive groups of Palæolithic implements. It is moreover free from the complication produced in the valleys north of the Thames by the presence of foreign-drift elements, for here the drift is restricted to débris derived from its own drainage-area.

The Darent Valley is one of the few ‡ which run through the Chalk escarpment into the so-called Wealden area §, though it does

* A general account of the drift-beds and denudation of this valley is given by Mr. Topley in his 'Geology of the Weald,' pp. 188-194, and 270, in Mem. Geol. Survey (1875), to which I shall often have occasion to refer. See also Messrs. Le Neve Foster and W. Topley's 'Superficial Deposits of the Valley of the Medway, etc.,' Quart. Journ. Geol. Soc. vol. xxi. (1865) pp. 443–474, and the Maps of the Geological Survey.

† Quart. Journ. Geol. Soc. vols. xlv. (1889) p. 270, and xlvi. (1890) p. 155.

‡ Another of these valleys, that of the Wey, was described in 1851 by the late R. A. C. Godwin-Austen in Quart. Journ. Geol. Soc. vol. vii. p. 278.

§ Taking the Wealden area to mean physiographically the whole of the area encircled by the escarpment of the Chalk.

not pass beyond the first outworks, being shut out by the range of the Lower Greensand from the central Weald. To the south of the Chalk range, the valley branches westward in the line of the main stream to near Limpsfield, and eastward to near Ightham in directions parallel with the ranges of the Lower Greensand and the Chalk, and is terminated by watersheds which separate it in the one case from the Oxted stream, and in the other from the Ightham stream (the Shode), both of which run from the foot of the Chalk hills, and flow into the central or Medway drainage-area of the Weald. The valley is thus isolated, and its basin is of very limited extent, though at one time it would appear to have been larger, in consequence of the greater importance of the affluents from the Tertiary area (see Map, Pl. VII.).

The first indent of the Darent Valley was, for the reasons given in two papers referred to in the last page, clearly subsequent to the deposition of the Lenham Sands, which are of Pliocene age, of the Red Clay-with-flints, and of the Southern Drift, while it commenced with the general great denudation of the Weald. It is therefore of late pre-Glacial or very early Glacial date *. At the former of these periods, the great valley separating the Chalk and Lower-Greensand ranges of hills was still bridged over by the Chalk and overlying strata, and it is to the denudation of these latter that both valley and escarpment are due (Pl. VI., figs. 1, 2, 3).

As the Lenham Sands are only of local occurrence, our object will be best answered by taking the Red Clay of the Chalk Plateau, with its sprinkling of Southern Drift, as our base-line. Without at present going into the question of the origin of the Red Clay-with-flints †, beyond mentioning that it is of local derivation, I may state that it is newer than the Tertiary strata, the outliers of which it encircles, while it seems to be older than the Southern Drift, with which it is closely associated.

Besides the main valleys of the Medway and Darent, the Chalk Plateau, with its "Red Clay," is intersected by a system of lesser valleys, which, starting near the crest of the escarpment, run northwards into the main valley of the Thames. These valleys commence on the Red Clay in very slight deflections on the surface, which rapidly increase in depth, and enlarge into the deeper valleys above which the Red Clay is left high on the adjacent plateau. These valleys, therefore, like the larger ones before named, are posterior in time to the Red Clay, as well as to the implement-bearing old drift with which the latter is associated. The difference of level between this older drift and the drifts of these other valleys, though

* In further proof of the sub-glacial action before noticed at the time of the Southern Drift (Quart. Journ. Geol. Soc. vol. xlvi. (1890) pp. 157, 174), I should mention that Mr. B. Harrison has since found on the summit of the Chalk escarpment at Terry's Hill above Wrotham, and at a height of 770 feet, some small angular boulders ('as large as quart measures') of the Oldbury chert, and several smaller blocks of Iron-sandstone from the Lower-Greensand range to the south.

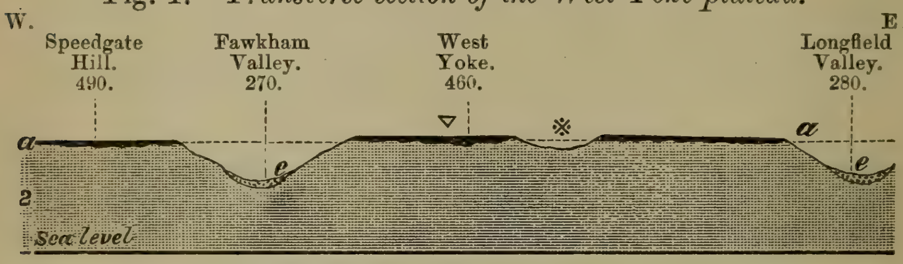
† For an account of this Red Clay, see Mr. W. Whitaker's 'Geology of London,' vol. i. chap. xviii. 1889.

necessarily small at the head of those valleys, equally indicates, as when the difference becomes greater, a marked difference of age. It will be our object to show the relation of both these valley-systems, with their drift-beds, to the Chalk-Plateau drift, and also to the Glacial and post-Glacial drifts of the Thames Valley *.

## § 2. The Chalk-Plateau Drifts and the associated Flint Implements.

Since the publication of my Ightham paper, Mr. Harrison has traced the rude Palæolithic implements of the Chalk Plateau to West Yoke, 1 mile N.W. of Ash, and very near to the line where the Red Clay with flints ends abruptly on the brow of the hill overlooking the lower plain of bare chalk, which, except where the Swanscombe Hills intervene, extends to the Thames (Pl. VI., fig. 2). The relation that the Red Clay with the associated Palæolithic implements here bears to the adjacent valleys is shown in the following section (fig. 1):—

Fig. 1.—*Transverse section of the West-Yoke plateau.*




*a*. Red Clay-with-flints.
*e*. Low-level valley-gravel.
2. Chalk.
▽. Site of Palæolithic implements of the Plateau-type.

(The vertical scale of all the general sections in the text, unless mentioned otherwise, is $\frac{1}{12}$ inch = 100 feet. The base-line represents the sea-level, and the figures which give the height above it are taken from the six-inch Ordnance maps, which are indispensable in work of this sort.)

The valleys on either side of the plateau at West Yoke are about 180 feet deep, while the small central depression (*), which eventually joins and belongs to the same valley-system, is here in an incipient state (10 to 20 feet in depth), showing that the mere question of level is not always conclusive in determining the relative antiquity of these drifts.

The great antiquity of the plateau-drifts can, however, be better realised by the N. and S. section (Pl. VI., fig. 2), which extends from the Lower-Greensand hills to the Thames, and shows the

* I use these terms for convenience, meaning to embrace the whole of the cold period from the earliest pre-Glacial to the latest post-Glacial times. The pre-Glacial, Glacial, and post-Glacial cycles pass one into another in a continuous series marked only by different and fluctuating degrees of intensity of cold. The term 'post-Glacial' conveys an incorrect meaning. 'Later-Glacial' would be a better term.

relation that these drifts bear to the river-drifts of the Thames Valley. This section passes through the summit-level of the Swanscombe Hills, which are there capped by Tertiary strata and an outlier of the older drift. Though the height of this hill does not much exceed 300 feet, it corresponds with the level that the gradient of the plateau at West Yoke and Ash should have, if extended thus far. North of this hill, at Milton Street, near the village of Swanscombe, and at a level here 200 feet lower than the plateau-drift, the high-level river-drift of the Thames Valley is met with. It contains flint implements of a distinct and more advanced type than those of Ash and West Yoke, while at a lower level still are brick-earths and gravel with Mammalian remains and implements of a yet later period. This is, I conceive, conclusive of the great antiquity of the Chalk-Plateau drift and implements, and if we are to assume, as there is every reason to suppose, that the great denudation of the valleys has been the work of Glacial times, then these implements may probably be assigned, as I have before suggested, to a pre-Glacial or early Glacial period.

The plateau which constitutes the table-land west of the lower Darent Valley presents features precisely similar to those at Ash, Bower Lane, and other places on the plateau east of the Darent Valley. There is the same spread of Red Clay-with-flints over all the Chalk Plateau, and the same slight sprinkling in places of a drift of much worn brown-stained flints, with a few subangular fragments of chert and ragstone from the Lower Greensand *. I have found this drift on the hills just above Shoreham. Chert and ragstone are particularly abundant in the field over the railway tunnel opposite Colegates Farm. They occur less abundantly around Halstead, and have been found by Mr. Harrison on the very summit of the escarpment, at a height of 700 feet, on Morant's Court Hill (see Pl. VI., fig. 3). Farther west, Mr. De B. Crawshay has found the brown-stained worn flints on Betsom Hill (790 feet) above Westerham, and on Titsey Hill (864 feet) above Limpsfield, both being on the crest, and forming the highest summit-levels of the Chalk escarpment. The intermediate ground between Morant's Court Hill and Betsom Hill has at present yielded no specimens, though the Red Clay-with-flints is continuous throughout. On the hill above Stonehouse, north of Halstead, I have found a considerable proportion of the brown-stained flints with numerous Tertiary flint-pebbles, some Tertiary sandstones, and a little Lower-Greensand débris.

At the time my Ightham paper was read, the only Palæolithic flint-implement known on this western plateau was the one at Currie Farm, south of Halstead †, found 20 years ago and described by Dr. John Evans. Its surroundings and position were such as to lead me to group it with the Ash specimens as of early Glacial or pre-Glacial age. My friend Dr. Evans, however, considered that

* I include any Lower-Greensand débris, such as grit and ironstone.

† The Rev. R. Ashington Bullen, the Vicar of Shoreham, has recently found a very similar specimen in the same field.

although it was found at the high elevation of nearly 600 feet, the position of the site above the extreme head of the valley of the Cray was so slight that this specimen might belong to the later or post-Glacial * drift of that valley, and not to the older level to which I would assign it. The lines of drainage of the Cray Valley being also from south to north confirmed him in this opinion †. If such a view could be sustained, it might invalidate the antiquity of the Currie-Farm specimen, and by inference the antiquity of those of the Ash district. But though it is true that both drifts are due to currents from the south, the one system of drainage which extended from the central Weald was in existence before the excavation of the Holmesdale Valley, whilst the other (the present Cray and its tributaries) dates from a period subsequent to the severance of the Chalk Plateau from the Lower-Greensand hills.

We now, however, have more decisive corroborative evidence of the age of the Currie-Farm specimen. Some time elapsed before any new locality was discovered in this district, but within the last two years Mr. De B. Crawshay has found similar implements at other localities on the N. of Halstead. The interest of these finds is that they occur on the northward prolongation of the Red-Clay plateau at a point where, owing to the valley gradient being more rapid than that of the plateau gradient, the difference of level between them—which near Currie Farm does not exceed a few feet—amounts to more than 100 feet. At one spot, $1\frac{1}{2}$ mile distant from Currie Farm, 480 feet above O.D., and a little north of Stonehouse (fig. 2), Mr. Crawshay has found seven flint implements, two of which are of the rudest Ash type and of the usual dark-brown colour, whilst five are of a light yellow colour and more closely allied to those found at Snag Lane (see p. 145). These latter were found on one of the Broke-Farm fields and may be of later date.

North of the valley and beyond the Halstead station, Mr. Crawshay found a large rude flake on Hewit's Farm at the level of about 470 feet, and more to the east, on the edge of Shacklands Wood (525 feet), two stained flakes. In another direction, on a hill where Tertiary flint-pebbles abound, west of Northstead Farm, he records four implements of the Ash type. All these places are on the Red-Clay plateau, here intersected by the dry upper Cray Valley and its tributaries, between which the Halstead and Northstead hills project as promontories, as shown by the plan and section on the next page, figs. 2 and 3. East of Well Hill, at the level of about 430 feet, Miss H. Waring found a pointed specimen of the Amiens type on Cockerhurst Farm, near Shoreham.

Farther westward, Mr. Crawshay has discovered on the highest summits of the Chalk escarpment three other implement-bearing localities. The first of these is at Betsom Hill, near Westerham, at the height of 750 to 790 feet; the second is a little off the summit

* 'Ancient Stone Implements of Great Britain,' p. 531.
† Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 295.

at Ivy Cottage, near Tatsfield, at the level of 780 feet, and the third at Titsey Hill, where the escarpment attains its greatest height of 864 feet (see Pl. VI., fig. 3).

Fig. 2.—*Plan of the Halstead and Northstead promontories.*

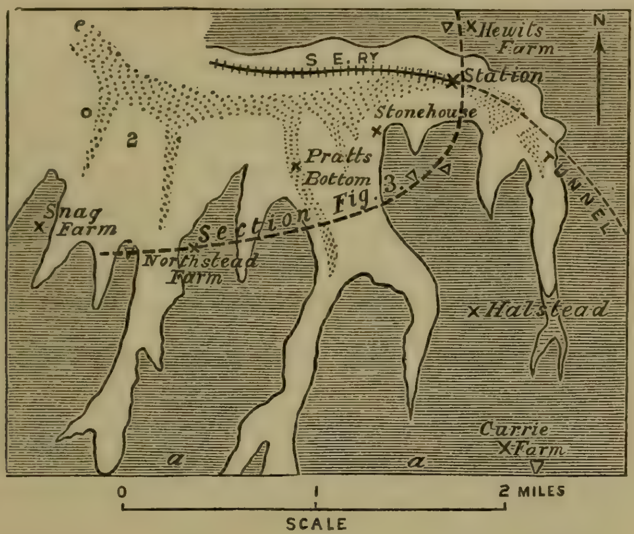
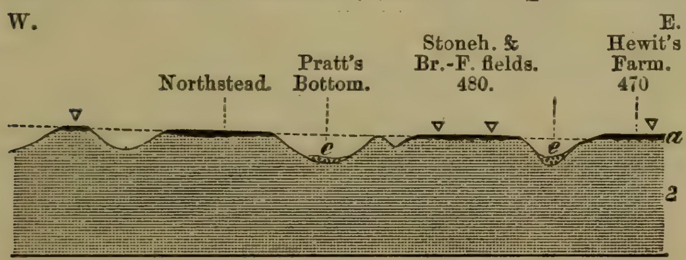



Fig. 3.—*Transverse section* (1) *across the promontories.*




*a.* Red Clay-with-flints and a sprinkling of the Southern Drift.
*e.* Unstratified Flint-gravel lying in the dry bed of the upper valley of the Cray and its tributaries. The only trace of fossils in this gravel was a small fragment of bone found near Pratt's Bottom, but at Green Street Green, two miles lower down the valley, where the gravel acquires much greater thickness, bones of Mammoth, Rhinoceros, Musk Ox, &c. have been discovered.
▽. Site of flint implements of the Plateau or Ash type.
o. Site of implements of the high-level River-valley type.
2. Chalk.

Still more recently, Mr. Harrison has found an outlier of the brown-stained-flint drift, together with some scarce rudely-fashioned flints, on the top of Morant's Court Hill, forming the very summit of the escarpment south of, and $\frac{3}{4}$ mile distant from, Currie Farm. They are scattered on the surface of two fields within the 700-feet contour-line. This ground cannot possibly be connected with any existing line of drainage, as it forms the summit-level of that part of the escarpment. Its position relatively to Currie Farm and Halstead, as

also to the escarpment, is given in Pl. VI., figs. 1 and 3, the former showing the gradient of the plateau from Morant's Court Hill to the Cray Valley, and the latter the relation of the hill to the adjacent part of the escarpment. These make it evident that the older drift is clearly independent of both the valley-systems, and that the drift on this Chalk plateau, like that on the Ash plateau, is of greater antiquity and distinct from that of the valley of the Cray and its tributaries.

The following lists, brought up to date, of the approximate number of specimens of the Chalk-Plateau or Ash type, found at the several localities above mentioned, will show how important this plateau-group has become. For those on the west plateau, with the exception of Morant's Court Hill and Currie Farm, I am indebted to Mr. De B. Crawshay, and for those on the east plateau to Mr. B. Harrison. Mr. Crawshay has likewise a considerable number of specimens from Ash, West Yoke, and Bower Lane.

*Chalk Plateau, West.* (See Map, Plate VII.)

| | Height above sea-level in feet. | Implements. | Flakes. |
|---|---|---|---|
| 1. Stonehouse and Broke Farm, Halstead * | 480 | 5 | 2 |
| 2. Shacklands Wood, field west of | 535 | 0 | 2 |
| 3. Hewit's Farm, Chelsfield | 470 | 0 | 1 |
| 4. Northstead, hill west of | 485 | 3 | 1 |
| 5. Betsom Hill, near Westerham | 790 | 15 | |
| 6. Titsey Hill, near Limpsfield | 864 | 3 | |
| 7. Ivy Cottage, Tatsfield | 780 | 8 | |
| 8. Currie Farm, Halstead | 590 | 2 | |
| 9. * Morant's Court Hill, S. of Halstead | 700 | 12 | |

Single specimens have also been found farther north at Park Gate, Lullingstone, and at Cockerhurst, both above the 400-feet level.

*Chalk Plateau, East.*

| | Height above sea-level in feet. | Number of Implements †. |
|---|---|---|
| 1. Ash | 490 | 80 |
| 2. South Ash | 520 | 60 |
| 3. West-Yoke Farm (1 mile N.W. of Ash) | 460 | 40 |
| 4. Kingsdown | 550 | 4 |
| 5. Peckham-Wood Corner | 637 | 2 |
| 6. Plaxdale Green | 630 | 2 |
| 7. Bower Lane (inclusive of Mr. Crawshay's specimens) | 520 | 30 |

But these ancient implements are not confined to the central area alone of the broad plateau. They extend, as on the west plateau, to the very crest of the escarpment, up to its highest summit-levels of between 700 and 800 feet (see Pl. VI., fig. 3). Mr. B. Harrison has found them at:—

* I also have found a few specimens at these places.

† A large number were moreover thrown away as duplicates, or as not worth keeping.

| | Height above sea-level in feet. | Number of Implements. |
|---|---|---|
| 1. Wrotham Hill | 760 | 6 |
| 2. Fairseat, near Wrotham | 690 | 2 |
| 3. Plot Farm (near Fairseat) | 697 | 2 |
| 4. Terry's Lodge Hill (above Yaldham) | 770 | 6 |
| 5. St. Clere's Hill (the fields by the side of Birches Wood) | 760 | 12 |
| 6. Drain Farm, above St. Clere | 725 | 10 |
| 7. Porter's Farm (near Romney Street) | 698 | 3 |
| 8. Cotman's Ash (above Kemsing) | 665 | 2 |

In several cases it is noticeable that the implements occur on or near small Tertiary outliers, as though they might have preceded the Red Clay-with-flints, and had been brought to the surface by subsequent denudation. At Ash Lower-Tertiary sands crop up on the surface; at West Yoke the same sands appear at a short distance; near Terry's Lodge a Lower-Tertiary clay was formerly worked; and at Bower Lane Mr. Crawshay found a bed of Mottled Clay (Reading Beds) under a thin bed of the Red Clay-with-flints. On the west plateau, sands and pebbles of the Woolwich Beds constantly appear in close connexion with the Red Clay. I mention this merely to draw attention to the fact and suggest further enquiry.

The question as to the probability of these implements having been dropped, like the Neolithic implements, at these places at a period subsequent to the plateau-drift *, has been before disposed of, for whereas the Neolithic implements have always remained on the surface and have undergone no alteration except a slight weathering and bleaching of their surfaces, these others are stained, spotted, and altered in a manner to show that they have been long embedded in a distinct matrix †, and have all the characters of the flints forming part of the drift with which they are associated. Still we want the confirmation to be afforded by finding them *in situ* in an undisturbed bed ‡.

As before mentioned, the shape of the plateau-implements is also of a peculiar character. They are mostly very rudely-trimmed flint-fragments taken from an old gravel, though there are exceptions to this rule, for, with the many rude specimens, a few of more perfect forms are occasionally met with. Thus a large ovoid implement, as well finished as those of Abbeville, was found at Bower

* One specimen recently found between Bower Farm and Romney Street by Mr. Bullen seems the result of such an accident. It is distinctly Palæolithic, and of the flat spear-head type so common in the post-Glacial beds of the valleys of the Thames and Somme, yet in general external appearance it resembles the Neolithic specimens found on the same ground, being of a uniformly dull white colour, slightly patinated and iron-stained at the edges by plough or spade, and showing none of the ferruginous incrustations or discoloration so general on specimens of the older or Ash type. The point is broken off by an old fracture. When perfect, it must have been 7 inches long by 4 inches wide at the haft.

† See Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 288 and pl. xi.

‡ Since writing the above Mr. Harrison has obtained a well-finished and well-preserved flat ovoid specimen, found at a depth of 2 feet in planting a tree at South Ash.

Lane, and a few better made specimens occur at Ash. Some might pass as specimens of the valley-drifts, but there is so far an almost entire absence of the highly-finished spear-head forms so common at those levels *. Nineteen out of twenty or more are rude ill-shapen stained flints with a small amount of work at the edges. Those figured in Plate VIII. are characteristic forms typical of this plateau-group. (See Explanation of Plate, p. 160 †.)

Fig. 1 in that Plate is merely the broken half of a Tertiary flint-pebble slightly trimmed at the edges for cutting or chipping. Another common form (fig. 2) is a piece of tabular or flat flint with flat edges, notched as though it had been used for breaking or shaping other flints. Others (fig. 3) are rude or natural flakes ‡ worked at the end for graving and scraping. Fig. 4 is a thick natural flake chipped at the edges and brought to a point; this specimen is interesting, as the type out of which the more highly-worked pointed implements so common in the later valley-drifts would seem to have been evolved. A very common form is a scraper in the shape of a crook, sometimes single (fig. 5), sometimes double (fig. 6), such as might have been used for scraping round surfaces like bones or sticks. There are other forms besides, but, with the few exceptions before mentioned, they are all merely rough natural fragments, picked out of the gravel, and more or less worked at the edges to adapt them to the simple wants of a people who seem at that time to have hardly been acquainted with the art of obtaining flints direct from the Chalk, as was done in later Palæolithic times. Such specimens exhibit the very rudiments of artificial work, and are often difficult to distinguish from natural forms. The interest which attaches to them is that they point to the very infancy of the art, and the application of the most common and readily available surface-materials to the fashioning of tools or weapons for use by early Palæolithic man.

It may be objected that the sites in the valleys of the Somme, Thames, &c., yielded so many finished specimens that the ruder forms have been overlooked; but this does not apply to those in this district, where the valley-specimens and plateau-specimens have received equal attention at the hands of Mr. A. M. Bell and Mr. Harrison, and none, however rude, have been rejected. Each series is completely represented in every respect.

The peculiarity of type by itself might not be sufficient, but taken in conjunction with the geological evidence, and subject to the reservation before mentioned, the evidence in favour of the great

* I see no force in the objection that, because a few rare well-finished specimens are found, the whole group must be judged by them. It only shows that there were a few superior workmen among the unskilled many. The suggestion that similar rude specimens may be found in the valley-gravels is at present without any proof.

† Both the rude implements and the brown natural flints with which they are associated are so alike stained, worn, and abraded, that it has even occurred to me whether they might not all have been washed down together from the old Wealden uplands.

‡ Artificial flakes are extremely rare on the Chalk Plateau. This implies the use of natural fragments, as the breaking down of blocks of flint from the Chalk would have led to scattered heaps of waste fragments and flakes.

antiquity of the plateau-specimens is, I think, conclusive. I may further remark that at Ash the Neolithic flints, which are found on the same surface with the Palæolithic flints, are in no wise different from the ordinary Neoliths found elsewhere on the Chalk and other surfaces. They are merely weathered white, have no colour-staining, and are readily distinguishable at first sight from the older forms.

Another feature to notice in connexion with these specimens is the amount of rolling and rubbing they have undergone. The flatter surfaces are sometimes covered with scratches, which occasionally bear a close resemblance to glacial striæ (Pl. VIII., fig. 7; see explanation of Plate); but I have seen none, unless it be the one figured, sufficiently regular to be ascribed with certainty to that cause, though the scratches are evidently of old date.

Occasionally a derived specimen of the older type is to be found in the newer drifts. Though more worn, they retain their dark-brown colour, and are easily distinguishable from the group with which they have become associated. I possess one of the type of fig. 6 (Pl. VIII.), found by Mr. E. Lewis at Limpsfield; Mr. Crawshay has two similar specimens from Snag Lane; and Mr. B. Harrison a rude scraper from West Yaldham, and another specimen from Crowdlesham. Other places might be named, but these will suffice and explain the presence of these ruder implements.

I had often met with stained and worn flints on the Sussex and Hampshire hills, similar in character to those of the Southern Drift on our own Kentish hills, but had not hitherto seen any flint implements of the old Ash type. Recently, however, Mr. Harrison has placed in my hands four such specimens, found by his friend Mr. R. Hilton, of East Dean, on the Chalk ridge * at Friston, near Eastbourne, and at the height of about 390 feet above sea-level, and of 200 feet above the level of the adjacent valley. Three of them are natural fragments of flint, slightly worked at the edges, one being similar to fig. 3 (Pl. VIII.). Another is a better finished pointed form, worked on both sides, and very much worn. They are of the usual dark-brown colour, and show much wear, and on one there are the same traces of ferruginous incrustation as that which is common on the implements found at Ash. This discovery tends to confirm a suggestion I made in a former paper † when speaking of the Southern Drift of the Thames Valley, that it was probable that on the southern slopes (in Sussex and Hampshire) of the Wealden highlands a similar drift was in course of formation at the same time, and that it was then subject to conditions analogous to those experienced by its equivalent in the London Basin.

## § 3. The Initial Stages of the Darent Valley.

I have before shown that in early Pliocene times a plain of marine denudation stretched across from the Chalk escarpment to the Wealden area, passing over the present Vale of Holmesdale, and that

* In the valley at East Dean Mr. Hilton had previously found Palæolithic implements of the ordinary river-valley type.

† Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 176.

in subsequent pre-Glacial times this plain was scored by streams flowing off a central mountain-axis*. The smaller streams, gradually becoming tributary to the larger one, centred in the Darent, and the excavation of the present valley then commenced. There is a gap or break in the sequence between the pre-Glacial drifts and the earliest of the so-called post-Glacial drifts of the valley, which is probably covered by the extreme Glacial epoch. It was then a time of erosion and denudation, and the record of it in this area is to be found, not so much in beds of drift and gravel, as in bared broad valleys and scarped ridges.

Of the earliest drift of the Darent Valley there is little that has escaped later denudation. The bank of coarse gravel on the brow of the hill on the west side of the valley between Eynsford and Farningham—a gravel abounding in a large proportion of Lower-Greensand débris and extending from the height of 280 to 360 feet —affords probably the best example.

The traces of flint drift scattered, in the upper part of the valley, on the slopes of the Lower-Greensand range, may possibly belong to this epoch, but I speak with doubt. Thus at Kent Hatch, above Westerham, at the level of 600 feet, there is a sprinkling of unstained subangular flints, with a few worn brown-stained flints, and there is a similar patch on the same level in the field to the west of the Union Workhouse, above Sundridge. At Fawke Common, near Sevenoaks, the same thing occurs. At the latter place, Mr. Crawshay has found a small, well-shaped flint implement. To these may be added the instance before mentioned of a thin covering of flint drift with some flint implements † at Bitchet and Stone Street, near Ightham, at the height of 530 feet ‡. Although these drifts are mere handfuls, they are significant, inasmuch as their materials are foreign to the area where they are now found.

Another minor fact pointing to an early stage in the erosion of the valley is the indication, which exists on the bare sides of the hill west of Shoreham, of an old line of water-level, at a height of 400 feet above O.D., or of about 200 feet above the present stream. At the point ⁎ (fig. 4) is a band of a compact breccia, about 10 to 12 feet broad, extending horizontally for some distance along the brow of the hill. It consists of angular fragments of chalk consolidated by a calcareous infiltration, and rendered so hard that it requires a smart blow with a hammer to break it. It appears to have been originally a talus of chalk fragments, such as would accumulate at the foot of a chalk slope or cliff, and to have been concreted by a calcareous cement into this brecciated rock by a spring charged with carbonate of lime in the manner of an ordinary travertine. But at this spot there is no impervious stratum to give rise to a spring. The Chalk, which rises to a height of 120 feet above the point (⁎),

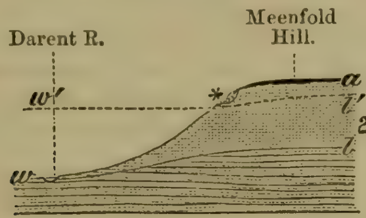
* Quart. Journ. Geol. Soc. vols. xlv. (1889) p. 291, and xlvi. (1890) p. 171 *et seq.*

† They are those which I have placed in the second or 'Hill' division in the Ightham paper.

‡ Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 276.

is perfectly homogeneous, and allows the surface-water to pass through it and descend to the underground water-level, *w l*—a level governed by that of the adjacent stream; and I can only account for a spring in the high position of (*) by supposing that one may have broken out there at the time when the bed of the valley had not been excavated to below that point, when the line *w′ l′* would

Fig. 4.—*Section of Meenfold Hill, Shoreham.*




*a.* Red Clay-with-flints.
*. Compact Chalk breccia.
*w l.* Present line of water-level.
*w′ l′.* Supposed former line of water-level.
2. Chalk.

represent the then level of the underground water, and consequently of the springs; for in that case springs would be thrown out on the higher level *w′ l′*, as they are now on the lower one *w l*, independently of any impervious stratum. This, therefore, may be taken as some evidence of the higher level probably occupied by the stream at that period.

## § 4. The High-Level or Limpsfield-Gravel Stage.

I have already had occasion to notice in a former paper* some of the few drift-beds in that branch of the Darent Valley which runs eastward from Otford to its watershed with the Shode—a tributary of the Medway. Those of the more important western or main branch of the Darent Valley running up to Westerham and Limpsfield Common have now to be noticed. (See Map, Pl. VII.)

The first appearance of a well-marked drift connected with the river-erosion of the Darent Valley is the high-level gravel on the watershed at Limpsfield Common. The denudation of the area had by that time made considerable progress; for the Chalk escarpment rises 200 to 300 feet, and the Lower Greensand 100 to 200 feet, above the level of this gravel-bed. With the exception of the few isolated traces named in preceding paragraphs, there is nothing to record the work of early excavation of the valley, though it is obvious, for the reasons before given, that the valley-erosion, which followed on the pre-Glacial rise of the land, must have continued through the succeeding Glacial epoch; and as there is evidence to show that extreme climatal conditions prevailed during that period in the Thames Valley, it may be presumed that ice and snow were

* Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 270.

then likewise effective agents in the denudation of this adjacent district. Before, therefore, the deposition of this river-drift, a valley of considerable width and 200 to 300 feet deep had been excavated between the Lower-Greensand hills and the adjacent Chalk plateau, by which the future Chalk escarpment was first brought into relief. This channel (which is on the line of the Gault) was subsequently worn deeper, and the escarpment loomed higher when, in later Glacial and post-Glacial times, river- and flood-action played a more prominent part.

But the present valley-channels at the base of the Chalk escarpment are not continuous along the whole length of the escarpment. They each have relation to the several rivers which drain the Wealden area, and each has its culminating point or watershed intermediate between these lines of escape. Thus the Darent, which drains into the Thames, is separated from the adjacent valleys draining into the Medway by narrow watersheds projecting as low ridges between the Chalk escarpment and the Lower-Greensand hills. This is a feature common throughout the great primary valley, which extends all along the base of both the North and South Downs, and is one of the many conclusive arguments against the marine origin of the escarpment, as that would necessitate a uniform level line for its base, whereas the line forms a succession of rises and falls (see line *mn*, fig. 3, Pl. VI.). Amongst the most remarkable of these watersheds or cols is the one which intervenes between the Darent and the Oxted stream—a small tributary of the Medway—at Limpsfield. Whilst in general these passes rarely rise to the height of more than 200 or 300 feet, in the Limpsfield case the summit of the pass which connects the Chalk range with that of the Lower Greensand attains a height of rather more than 500 feet above O.D. The relation of the pass to the adjacent ranges and river-basins is shown in the sections on the next page, figs. 5 and 6.

The position of the gravel on the watershed is so equally balanced between the Darent and the Oxted Valleys that, independently of other evidence, it would be difficult to decide to which of the two it belonged. But, as I shall have occasion to explain farther on, it shows so close a relation with other beds of gravel lower down the Darent Valley that I quite concur with Mr. Topley * in placing it in that valley-system, and we can only suppose that the original ridge separating the two valleys, of which Westheath Hill, which is 516 feet high and bare of drift, may be a remaining portion, has been removed by denudation subsequently to the deposition of the gravel.

The character of the Limpsfield gravel is very distinct. It consists altogether of débris from the Tertiary strata and the Chalk, with the exception of a small portion derived from the substratum of Lower Greensand. A fine section of it is exposed in the old pit on the north side of Limpsfield Common. It is there from 8 to 10 feet thick, and is composed of the following materials—given in the order of their relative abundance—embedded in loam and clay

* Topley, 'Geology of the Weald,' pp. 193 and 289.

of a burnt-sienna colour, in places mottled with yellow, and roughly heaped or piled together without apparent bedding, although there are here and there lenticular seams of sand and loam, and resting on a nearly level base of Lower Greensand :—

1. Tertiary flint-pebbles of all sizes—some very small and some broken—in profusion. Mixed with these in a nearly equal total are—
2. White flints, many in small angular fragments, some subangular and worn, and some in large blocks but little altered.
3. Many angular fragments of through-stained yellow flints.
4. Some subangular fragments and a few large blocks (one 20″×20″×8″) of iron-sandstone.
5. A few brown-stained, much-worn flints.
6. A few worn pieces of Tertiary sandstone and Pudding-stone.
7. A very few rare, light-coloured, flat, ovoid quartzite pebbles.

Fig. 5.—*Section along the watershed at Limpsfield.*

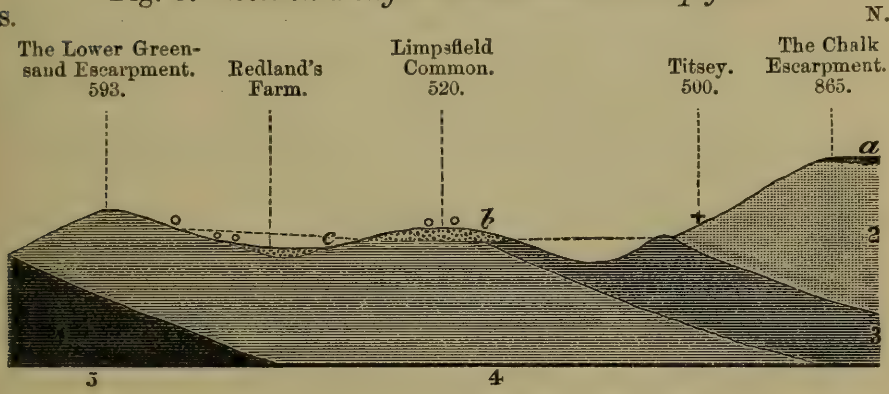
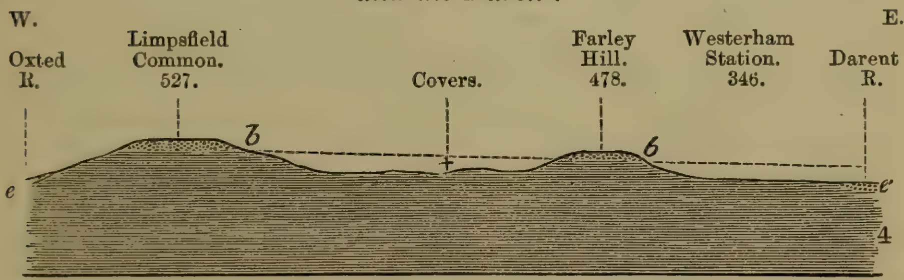



Fig. 6.—*Section across the pass between the Oxted stream and the Darent.*




*a.* Red Clay-with-flints of the Chalk Plateau.
*b.* High-level ochreous flint-gravel.
*c.* Brick-earth and trail.
*e.* Low-level Gravel.
o. Site of Palæolithic flint-implements of the high-level valley type.
2. Chalk.
3. Upper Greensand and Gault.
4. Lower Greensand.
5. Upper-Wealden strata.

The Iron-sandstone comes from the underlying Lower Greensand, and the quartzite-pebbles are derived, not from the New Red

Sandstone, but from the pebble-beds of Lower-Eocene (Woolwich) age.

The composition of this gravel renders it obvious that it is derived from the Chalk and Tertiaries on the hills to the north of Limpsfield. The escarpment is there capped by the Red Clay-with-flints, with isolated outliers of Tertiary strata. One of the most important of the latter, consisting chiefly of a mass of flint-pebbles, occurs at Worm's Heath, three miles north of Limpsfield. It has there been much disturbed, and the pebbles are mixed with numerous angular and subangular flints. Elsewhere on the escarpment there are some less disturbed pebble-beds. The escarpment at Titsey above Limpsfield rises to the height of 800 feet to 866 feet, but there are depressions where the level is from 50 to 100 feet lower, while near Warlingham there is a gap which is still lower by 100 feet, and bare of the Red Clay. It may have been through some of these that the streams of Tertiary pebbles, and the flints from the Red Clay and the Chalk, descended into the then flat and broad valley between the Chalk and Lower-Greensand range; while it is to be observed that, although the Lower-Greensand range, $\frac{3}{4}$ mile south of the Limpsfield gravel-pits, is capped by beds of Chert and Ragstone, no fragments of these have been met with in that gravel, although they are common in the adjacent brick-earth pits.

No organic remains of any description have been discovered in the Limpsfield gravel *, though it has been worked for many years. Mr. A. Montgomery Bell has, however, found a large number of Palæolithic implements on the Common, and over the adjacent fields of Broomsland Farm on the very summit of the watershed (see figs. 5 and 6). They are mostly of the pointed and ovoid types, similar on the whole to the smaller Amiens implements, or to those I have named "the hill-group of Ightham"†. From their position, there was reason to suspect their connexion with the underlying gravel; but it was possible, on the other hand, that they might be associated with a wider spread of the adjacent brick-earth, which belongs to a subsequent stage. It was long before that point could be established, for though a few worked flakes had been discovered from time to time in the gravel, it was not until last year that Mr. Bell obtained a large, well-finished, pointed implement, grey and patinated, of the ordinary St.-Acheul type. I will not enter further into the discovery and spread of these implements, as they will, I hope, shortly be described at length by Mr. Bell, to whose persevering researches their discovery is due.

As the Drift-gravels of the Darent Valley have been described by Mr. Topley, I need only notice them so far as they assist in connecting the Limpsfield bed with known horizons in the Thames Valley, or with those drift-beds that have been brought to light by sections made since the date of his memoir. He remarks of the Limpsfield gravel that the most interesting point about it is that it

* I first visited this and the adjacent pits in search of Mammalian remains in 1849.

† Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 284, and pl. x.

lies *on the watershed* *, and, though related to the Darent Valley, cannot be referred to that river in its present form †. He observes also that it is quite certain that the gravels of the Darent Valley westward of Westerham have a distinct relation to that of Limpsfield (*op. cit.* p. 193). In this I quite agree, but I would extend the relation considerably beyond these limits; for, although the detached outliers lower down the valley are affected by local conditions, their general characters are alike.

It is in this older and wider floor, of which only few portions now remain, that the present valley-channel has been excavated. One of these remaining portions caps Farley Hill, near Westerham, two miles east of Limpsfield Common, and a short way north of the course of the Darent (fig. 6, p. 139).

The bed of gravel there is not so thick as at Limpsfield, and, like it, is unstratified or very rudely bedded, and consists essentially of angular and subangular flints with Tertiary flint-pebbles, but the latter are in less proportion. Fragments of iron-sandstone from the Lower Greensand are common, with a few rare specimens of Lower-Greensand grit and of pieces of Tertiary conglomerate. There are no organic remains, nor have any flint implements been hitherto found, but there has been no long and sustained search like that Mr. Bell has made at Limpsfield ‡. The difference of level between the two beds is 51 feet, which gives to the old river-channel a gradient of 25 feet to the mile.

On the opposite side of the Darent, in the grounds of Squerryes Court, and at a similar level (478 feet) there are traces of the same gravel. These outliers are on a level of 116 feet above that of the present stream of the Darent. Mr. Topley describes another small outlier on the roadside E. of Squerryes Court and at about the same level, and one on Moorhouse Common, between Limpsfield and Westerham, at the height of 485 feet §.

From Farley Hill no high ground breaks the view for a distance of five miles down the centre of the valley. The few patches of the high-level gravel are all on the south side of the valley, and lie on the slope of the Lower-Greensand hills. One is to be seen in a small pit in the south-east corner of the grounds of Brastead Park ‖, 2½ miles from Westerham, and at a height of about 430 feet above sea-level. The gravel is very similar to that on Farley Common, but is more sandy and with more Lower-Greensand débris, including large blocks of Iron-sandstone, and some fragments

* On the east branch of the Darent Valley there are analogous but more obscure remnants of gravel on the watershed at West Yaldham and on the north slopes of Oldbury (see Pl. VI., fig. 1, and p. 143).

† For Mr. Topley's discussion on this question, see 'Geology of the Weald, pp. 289, 297, 298. He thinks the original river must have taken its course farther to the W. or S.W. than now.

‡ From this hill one has an excellent view down the valley, showing the relation which this gravel bears to the Darent, to the Chalk Downs, and to the Lower-Greensand range.

§ 'Geology of the Weald,' p. 194.

‖ *Op. cit.* pp. 191, 192.

of Ragstone, but there the Lower-Greensand hills are prolonged above the pit. Between Sundridge Place and Dryhill, nearly a mile farther down the valley, is another well-marked outlier forming a small knoll a little above the 400-ft. contour-line. This gravel, which is very sandy, is not worked, and we can therefore judge of its composition only from surface exposures. These show it to consist of:—

1. Angular and white, and other slightly subangular flints.
2. Tertiary flint-pebbles of all sizes.
3. Subangular pieces of Chert, Ragstone, and Ironstone, much worn.
4. Numerous very subangular brown-stained flints.

I could not determine their relative proportions, but the large proportion of Lower-Greensand débris, and of the stained flints, mostly of small size, is very noticeable. Many of the flints show the ragged sponge-structure so common with some of the layers of flint near the summit of the Chalk escarpment. I noticed also a large piece of much-worn Sarsenstone *.

From Farley Hill to the Sundridge outlier (410 feet) is a distance of a little over three miles, and the difference of level amounts to 68 feet, giving a gradient of $22\frac{2}{3}$ feet to the mile, or taking the whole distance from Limpsfield, of 24 feet to the mile.

In descending the valley from Sundridge, the next important outlier is on the opposite side of the Darent, and, like the outlier at Farley, it rises considerably above the surrounding plain. This gravel, which caps Broughton Hill †, near Dunton Green (Pl. VI., fig. 1), is more stratified than the Limpsfield bed, and contains a less proportion of Tertiary flint-pebbles, and a larger proportion of Lower-Greensand débris; but this arises from its being farther from the source of the Tertiary pebbles, and from the increased number of affluents from the Lower-Greensand hills. It more nearly resembles the Sundridge-Knoll gravel, consisting, in the order of relative abundance, of:—

1. Subangular Chalk flints of all sizes, with some angular ones.
2. Numerous Tertiary flint-pebbles.
3. A good many subangular Chert and Ragstone fragments.
4. Much worn and stained brown and ochreous flints.

Embedded in a light brown or reddish clay, with some seams of sand.

This hill is 357 feet high, and $2\frac{1}{2}$ miles distant from the Sundridge outlier, which, taken at 410 feet, gives a difference of level of 53 feet, or a gradient of $21\frac{1}{2}$ feet per mile, but the line here drawn is a little devious.

A short distance beyond, the two branches of the valley meet, and pass through the Chalk escarpment. The few high-level gravels in the eastern branch of the valley are still more fragmentary and imperfect than those in the western branch. I have before mentioned

* Mr. Topley also mentions a patch of gravel in Montreal Park, a little above the 300-ft. contour-line. I have not seen it, and cannot say whether it belongs to this or to the next stage, as may also the traces of gravel on the top of the railway-cutting through the hill adjacent to Riverhead.

† 'Geology of the Weald,' p. 189. Mr. Topley saw the railway-cutting when freshly made.

the patch of gravel on the northern slopes of Oldbury at the level a little above 400 feet, and that on the hill north-west of Seal at about 300 feet *, which seem to belong to this stage. Flint implements occur with both.

A better marked case which I have since had occasion to observe occurs at West Yaldham, near the east-lodge entrance to the grounds of St. Clere (Pl. VI., fig. 2), at the height of about 430 feet. The ground is there thickly covered with gravel (the depth not known), consisting of:—

1. White angular and slightly subangular flints.
2. Some flints of very large size.
3. A few brown-stained subangular flints and Tertiary flint-pebbles.
4. A very few subangular fragments of Chert, Ragstone, and Iron-sandstone.

Some fragments of the Oldbury-Hill stone, and a broken piece of a Palæolithic implement of the flat ovoid form, together with a scraper of the Ash type †, have been found here by Mr. B. Harrison. This bed, with that on the flanks of Oldbury, seems to mark the watershed between the Darent and the Shode; but whereas the centre of the watershed at Limpsfield between the Darent and the Oxted stream is capped by the gravel, it has here been removed from the centre, and only the lateral ends of the bed remain.

Again, in a field between Otford and Kemsing, and at a height of 300 to 330 feet ‡, there is a patch of gravel composed mainly of angular and subangular white flints, with a few brown-stained worn flints and Tertiary flint-pebbles, and very few fragments of Chert and Ragstone. This bed lies on a spur of the Chalk at the base of the escarpment below Beechy Lees.

The more contracted valley through the Chalk north of Otford, on which we now enter, has been so entirely denuded that few traces of the older drift-beds remain.

The best marked outlier is above the paper-mills at Eynsford, on the right bank of the river, close on the 200-feet contour-line, whence it extends to the height of 220 or 230 feet. A small cutting on the lane-side shows a section of this gravel 4 to 5 feet deep, roughly bedded, and consisting of Chalk flints, Tertiary pebbles, subangular fragments of Chert, Ragstone, and Ironstone (L.G.S.), with a few old brown-stained flints. The bed extends northwards towards Beesfield, and reappears on the slope of the hill east of Farningham, where it may be seen in the bank on the roadside at about the same level. The distance between this spot and Broughton Hill being $5\frac{1}{2}$ miles, and the difference of height 137 feet, gives a gradient of 25 feet per mile, an increase probably connected with the more contracted valley-channel and a greater velocity of the stream.

* 'Geology of the Weald,' p. 191.

† This is in all probability derived from the plateau-drift.

‡ From the same level, in the grounds of Wildernesse, near Seal, Mr. Crawshay has two porcellanous-looking small implements, well shaped, with the edges sharp and uninjured.

Below Farningham, beds of gravel are more frequent on the right bank of the valley, while the left bank remains bare until within three miles of Dartford. On the hill above Dartford Powder Mills, a thick and far-spreading bed of gravel sets in; it extends to the high road and the North Kent railway-cutting. The mean height of this bed above O.D. may be taken at 112 to 100 feet; and as the distance from Eynsford Mills is five miles, this is equal to a gradient of about 22 feet to the mile. On the whole, therefore, the gradients from Limpsfield to Dartford show a remarkable agreement, although owing to the few and distant points of observation between Broughton Hill and Dartford, and the greater uncertainty of these levels, the intervening gradients may require some correction. Enough, however, is established to show that the fall of the stream of gravel is continuous, and analogous to that of an ordinary river-bed.

The gravel at Dartford forms part of the great sheet which extends westward over Wilmington and Dartford Heaths, and eastward to Stone and Milton Street, near Swanscombe. It is from 10 to 20 feet thick, is roughly stratified, and consists of subangular flints, with a large proportion of Tertiary flint-pebbles, and numerous worn fragments of Chert and Ragstone—some of which are of considerable size. But in addition to the large contribution brought by the old Darent from the Chalk and Lower-Greensand hills, there is in the gravel of Dartford Heath and Stone a certain proportion of Triassic red quartzite-pebbles, white quartz, and other old rock-pebbles (veinstone, granite, &c.) derived from Boulder-clay series north of the Thames, which serve to connect this bed with the great spread of High-level gravel of the Thames Valley.

From a consideration of the facts now described, there is reason to conclude that the Limpsfield gravel must be correlated, not with the High-plateau gravel with which it assimilates in respect to its level, but with the Upper Terrace of High-level gravel of the Thames, and therefore that it is of later Glacial or so-called post-Glacial age. There are, no doubt, breaks in the sequence, but allowing for the fall of a turbulent stream, the prevalence of a considerable degree of cold, and the subsequent extensive denudation, of which there is sufficient evidence, the separate outliers exhibit so close a relationship that I cannot doubt their common origin. The Palæolithic implements also of the Limpsfield watershed agree in their general characters with those which I designated temporarily as the "Hill Group" of the Shode Valley or the high-level river-gravel, and not with the older group of the Chalk Plateau, or with those of the lower levels of the Thames and Medway.

### § 5. Contemporaneous Drift in the Cray Valley.

Another discovery of Palæolithic implements bearing a general resemblance to those of the Limpsfield gravel, and agreeing with it in geological position, has recently been made by Mr. De B. Crawshay near Green Street Green, in the valley of the Cray. They are spread over the surface of a gravelly field on the side of the lane

leading from the high road up to Snag Farm, and at about ¼ of a mile from the high road. Mr. Crawshay has collected from this locality 40 pointed and ovoid Palæolithic implements, and 18 flakes and scrapers. Two Palæolithic specimens had previously been found near this spot by Mr. P. Norman *. Nevertheless they are rare, for four of us, after a full hour's search, only succeeded in finding five indifferent specimens. These implements are of the "Hill" type, and mostly stained a light yellow colour †.

The stream of gravel at Pratt's Bottom and the upper Cray (fig. 2, p. 131) descends the Cray Valley, and passes by the end of Snag Lane to Green Street Green, where it is very largely developed. Remains of the Mammoth, Tichorhine Rhinoceros, and the Musk Ox have been found in the great pit on the Green, and in a side pit I have discovered a few specimens of *Pupa marginata*, but could find no other shell ‡. The level of this drift at the end of Snag Lane is 276 feet above O.D. The field up the lane where the implements occur is on the level of 320 to 340 feet, or 48 feet higher, whilst farther on the Red Clay-with-flints caps the hill at the height of 450 feet. We there have therefore the three levels of drift perfectly well-marked. I doubt, however, whether the Green-Street-Green gravel is really a river-drift, and hope to describe it on some future occasion.

It is at the farther end of the Cray Valley, near Crayford, that Mr. F. C. J. Spurrell found the remarkable spot where Palæolithic man worked, and fashioned the Chalk flints into shapes most conveniently adapted for his tools and weapons—a spot now covered by 30 feet of Mammaliferous brick-earth and drift §. It is to be hoped that these discoveries will be followed up, and that further evidence of man's early habitation at other places in the Cray Valley may be forthcoming.

## § 6. The Brick-earths of the Darent Valley.

These are few in number. The bed of most importance is the one worked on the south side of Limpsfield Common, a short distance from the gravel-pit (*c*, fig. 5, p. 139). It lies in a slight depression near the head of the present Darent Valley ‖, at a height of 470 feet above O.D., or from 10 to 30 feet lower than the adjacent gravel-

* These implements, together with the Mammalian remains from the pit at Green Street Green, are now in the collection of Sir John Lubbock at High Elms.

† Quart. Journ. Geol. Soc. vol. xlv. (1889) pl. x.

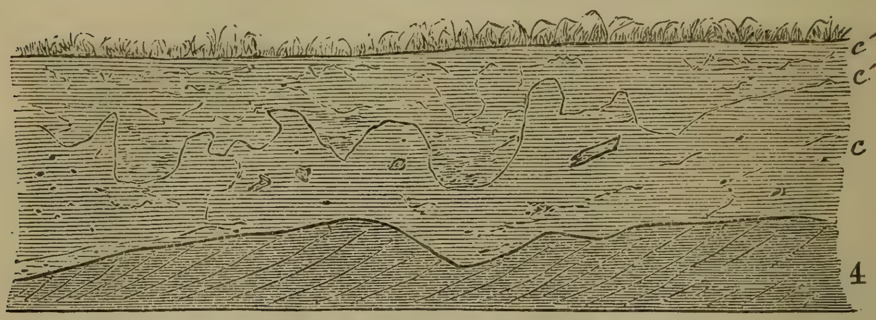
‡ No Palæolithic implements have yet been found in the large pit, though careful search has been made, but from this smaller pit on the other side of the hedge Mr. Crawshay has obtained five specimens. They are of a dark yellow colour, very much rolled and worn, and seem to me derived either from the Plateau drift, or from a high-level valley gravel such as that at Snag Lane. One of the specimens was found at a depth of 16 feet, close on the Chalk.

§ Quart. Journ. Geol. Soc. vol. xxxvi. (1880) p. 544.

‖ It seems as much related to the Oxted Valley as to that of the Darent, but subsequent denudation may have caused this, and in any case there is a close connexion with the Limpsfield gravel. See also 'Geology of the Weald,' p. 194.

bed, but the two beds are nowhere seen in superposition. The brick-earth attains its greatest height at Gibb's Farm and Trenchleys, rising there above the 500-feet contour-line, while it extends ½ mile westward to Westheath at about the same level, but it is not worked at these places.

Fig. 7.—*Section at the Brick-earth pit, Limpsfield Common.*




$c''$. Weathered surface, bleached ........................................ 1 foot.
$c'$ Disturbed brick-earth } with angular débris... 8 to 10 feet.
$c$. Undisturbed brick-earth, unstratified, }
4. Lower Greensand—a soft loamy grit.

This brick-earth is very stony, and no fossils of any sort have been found in it. Unlike the gravel, the rock-débris in it consists in greater part of angular fragments of the Chert, Ragstone, and Ironstone (with some of the latter subangular and of large size), from the Lower Greensand to the south of the pit, mixed with which are angular and subangular flints, and Tertiary flint-pebbles derived from the gravel on the north. These are scattered irregularly and at all angles through the brick-earth. The bed exhibits possible glacial influences, not only in the irregular distribution of the stony débris, but also in its indented surface, which shows disturbance by action from above (may be floating ice), causing contortion of the bed, and which has tilted a number of the blocks and pebbles upright on their longer axes. Occasionally a seam of fine gravel has been caught up and dovetailed into the base of $c'$, so making the line of separation between $c$ and $c'$ more distinct.

In this pit Mr. A. M. Bell has discovered a few Palæolithic flakes and implements. He has also found a well-shaped flake at a depth of 3 feet in undisturbed brick-earth on Gibb's Farm. The brick-earth continues a short distance eastward, following the course of the swale, which gradually enlarges eastward towards the Darent, and it is in a field on Redland's Farm, over which there are traces of this brick-earth or of trail, that Mr. Bell has found the greater number of the flint implements in his collection. These, in his opinion, have been brought to the surface by the circumstance of the ground having, a few years ago, been grubbed up and trenched to the depth of 1 to 2 feet.

Lower down the valley no brick-earth has lodged except in a few sheltered places. There is a small bed worked at Covers, near

Westerham, but this has more the appearance of a wash from the Gault. Mr. Topley mentions that a brick-earth 10 feet deep has been dug near Sudbridge Church, and that brick-earth extends from Dryhill eastwards towards Briton's Farm, which would be near to the 400-feet contour-line. A newer brick-earth is worked at Froghole Farm, near Chipstead, overlying some Low-level ground.

The powerful scour of the waters, as they ran through the narrower pass in the Chalk hills, has either not allowed of the lodgment of brick-earth or else has swept it away, and it was not until the current was checked near Dartford by its junction with the Thames that sedimentation of brick-earth took place*. That period may have been somewhat later.

### § 7. Other Drifts of the Darent Valley: the Chevening and Dunton-Green Gravel.

A sprinkling of gravel is common over much of the lower grounds of the Darent Valley, but it is only in a few places that the quantity amounts to a well-defined bed, and the relation of these to one another is more uncertain than is that of those belonging to the Limpsfield level. I give them in what appears to me to be their order of succession, but with the certitude only that they are all newer than the Limpsfield bed.

*The Chevening and Dunton-Green Bed.*—It was not until the railway from Dunton Green to Westerham was made (1881–82) that the distinctive character of this gravel, or the fact that it was anything more than a superficial trail, could be determined. The railway sections then made it evident that it formed occasionally a well-defined and more or less continuous bed, resting frequently upon a very irregular surface of Gault—in the form of patches or pockets of lesser or greater extent.

At Dunton Green (the railway-bridge cutting) it forms a compact and continuous deposit, without bedding, about 5 feet thick, and composed, in the order of their relative abundance, of:—

1. Large and small angular or slightly subangular flints (some stained through of a light yellow colour), these form the great bulk of the gravel;
2. Some large, fresh-looking, perfectly angular flints
3. A moderate number of Tertiary flint-pebbles and subangular fragments of Sarsenstone and Ironstone;
4. A very few well-worn brown-stained flints;

embedded without order in a matrix of red loam and sand. No fossils and no flint implements have been found in this gravel. Its level here is 270 feet above O.D., or 87 feet lower than that of the adjacent Broughton-Hill (Pl. VI., fig. 1 and fig. 10) high-level gravel, and there seems to be an absence of Chert and Ragstone. But in a pit recently opened a few hundred feet south of the railway bridge, a few rare pieces of cherty Ragstone are to be

* The high-level brick-earths of the eastern branch of the Darent Valley were noticed in the Ightham paper.

found; and as this stream of gravel sweeps round the hill, it catches up from the eastern branch and other affluents a quantity of Lower-Greensand débris, so that, on the other side of the hill, between New Barn and Rye House, it contains a large proportion of Chert and Ragstone, together apparently with some of the Broughton-Hill gravel trailed down the hill. The features distinguishing these two gravels are:—

1. The larger proportion of Tertiary flint-pebbles, and of brown-stained worn flints, in the Broughton-Hill bed, and its well-marked stratification.

2. The great preponderance of angular and subangular flints in the Dunton-Green bed, and its want of stratification.

The railway-cutting at Dunton Green was too far advanced when I first saw it, and the gravel-bed too massive, to mark the peculiarity of its junction with the Gault shown in the longer shallow cutting between Chevening Cross and Combe Bank Wood, where the sections were at first sight curiously deceptive. The sides of the cutting, which had been reduced to a slope of about 30°, presented the appearance shown in fig. 8, exhibiting loops sloping downwards and sideways towards the west; while on the south side of the cutting they sloped towards the east. But where the side had been left vertical the section was as represented in fig. 9. The appearances of distortion are therefore due solely to the obliquity of the plane intersecting the cylindrical segments of gravel *.

Fig. 8.—*Cutting, 5 feet deep, on north side of the line between Combe Bank and Chevening, after being sloped down.*

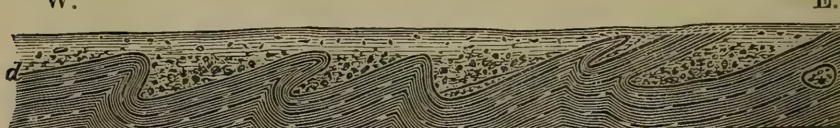
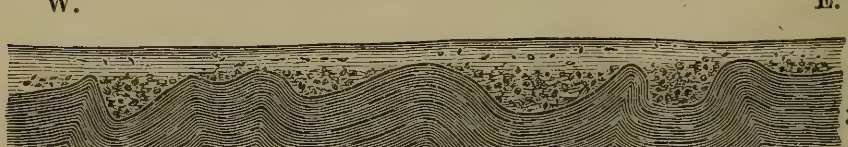



Fig. 9.—*Cutting on north side of the line by the bridge adjoining Combe Bank, before being sloped down.*




*d.* Unstratified gravel, sand, and clay. This bed consists of two parts, which pass one into the other—a lower one of coarse gravel in a matrix of ferruginous loam and sand, mixed with some clay from the Gault; and a thin upper one, *d'*, which spreads nearly uniformly over the whole, of a light-brown clay (altered Gault) mixed with a few flints.

3. Bluish-grey Gault.

The gravel in *d* consists of:—
Angular and subangular white flints in larger part.
Some Tertiary flint-pebbles.
A few small blocks of Tertiary sandstone and ironstone.

* A full explanation of this phenomenon is given geometrically by the Rev. O. Fisher, Geol. Mag. dec. ii. vol viii. (1881) p. 20.

The ground is nearly level, and from 320 to 340 feet above O.D., or about 60 feet above the Darent at Sundridge, with a slight incline southward, succeeded by a more rapid fall as we approach the river.

The gravel lies in pockets and troughs, having a general strike towards the north-east and south-west, and the line of separation between the Gault and the gravel is clean and sharp. No loose stones penetrate the Gault. It is as though the gravel had been pushed bodily into the clay, which presented on the steep sides of the pockets strongly marked slickenside-surfaces with the striæ directed downwards. Had the cavities been formed by running water they would have inosculated one with another. But such is not the case. Each seems separate and independent, and formed by a process of punching, which could only be produced by force or pressure, such as might be caused by a weight of ice or snow.

The composition of the gravel is also exceptional, many of the flints being of large size, perfectly angular, and identical with those in the Red Clay-with-flints on the summit of the escarpment, which rises at a short distance beyond; while adhering to their interstices was some of the same Red Clay. Besides these, there were a few Tertiary flint-pebbles, which also are common in places in the Red Clay-with-flints, but no Lower-Greensand débris. There seem to be, therefore, grounds for supposing that this drift-bed has been derived directly from the bed of Red Clay on the escarpment above.

Near the outlier of Limpsfield gravel on Sundridge Knoll, but 100 feet lower, there is another bed of gravel capping a low hill at the level of 300 feet, and composed in great part of Lower-Greensand débris, Tertiary flint-pebbles, brown-stained flints, and with comparatively few white subangular flints. Whether this represents the southern or Lower-Greensand border of the Chevening gravel stream, or whether it belongs to a subsequent stage, I am unable to say.

From Dunton Green, the Chevening Drift apparently sweeps round the eastern side of Broughton Hill by Rye-House Farm, but no sections are exposed. On the slightly rising ground ¼ mile S.W. of Otford, and about 20 feet above the Darent, or 220 feet above O.D., a coarse unstratified gravel, 4 to 5 feet thick, possibly of this age, or a stage newer, is worked. It consists of:—

1. Angular and subangular white flints, mainly.
2. Some Tertiary flint-pebbles.
3. A certain proportion of subangular Chert and Ragstone.
4. A few dark brown subangular flints.

The whole confusedly heaped together in a slight matrix of reddish-yellow clay and loam. This bed, which reposes on an uneven surface of Gault, is, however, on a lower level, and contains more Lower-Greensand débris than at Dunton Green; but this may be due to a more rapid gradient, and to the junction of the eastern branch of the valley with other tributaries from the Greensand Hills (see Map, Pl. VII.).

Nor is any bed of this age clearly seen to the west of Combe

Bank. It appears to ascend to a level higher than that of the railway, for it does not show in the cuttings beyond Combe Bank. The only place where I have seen anything like traces of it has been near Ivy House, one mile north of Westerham (430 feet), where there is a sprinkling of drift similar to that of Chevening, but there are no sections to prove it. This would give a gradient from Combe Bank of about 32 feet per mile, while that from Combe Bank to Dunton Green is equal to 35 feet per mile. This gradient, if prolonged, would rise nearly to the summit-level of the depression or gap on the north side of the Limpsfield watershed, corresponding with the one before mentioned on the south side of the summit-level (see fig. 5, p. 139).

The various circumstances I have mentioned in connexion with the brick-earth of Limpsfield Common, and with the Chevening and Dunton-Green Drift, would seem to warrant the belief that they are connected with a temporary return of glacial conditions *, following, after an interval of milder seasons, the more polar cold to which may be ascribed the previous vast glaciation of the district—a glaciation that had already outlined the great physiographical features of the country. It is difficult to account for the disturbed state and the peculiar condition of the brick-earth at Limpsfield, for the blocks of gravel rammed into the Gault at Chevening, or for the presence in the same gravel of the Red Clay with its flints in a state so little altered,—otherwise than by the presence of ice and snow, and by the removal of the original material from the higher to the lower level in a frozen mass. A drift of that character could not have been formed by river-action, as that would show wear, and a structure in accordance with such action, of which this gravel possesses none.

It is also to be noticed that, after the gravel was pressed into the Gault, the surface was apparently planed over, so as not only to level any inequalities of the ground, but also to carry forward some portion of the Gault, and spread it as a top layer, 1 to 2 feet thick, over the whole (*d'*, figs. 8, 9), in a way which suggests the passage over it of a heavy weight. Another feature in connexion with this drift is the number of flints here and at the other places (Wray Common, near Reigate, for example), pitted or pock-marked —a condition owing not improbably to extreme cold.

The prevalence of a temporary cold period might also serve to explain the presence of some patches of angular Lower-Greensand drift on the lower levels between Westerham and Chipstead, and the occasional occurrence of blocks of Lower Greensand of considerable size. Mr. Topley notices several (one $17'' \times 8'' \times 4''$) near Sundridge, and there used to be a block on the side of the road, about ¼ mile east of the Paper Mill. Lower down the valley there are several large blocks of Tertiary sandstone derived from the strata on the adjacent Chalk plateau. Some of these lie in the field on a low level between Otford and the brick-pits, and a block

* I shall have occasion to adduce corroborative evidence afforded by similar conditions in the Thames Valley.

of about a ton in weight of a sandstone-and-flint-breccia (Lower Tertiary) may be seen on the side of the road north of the Kennels at Otford. It is probable that there were others which have been broken up.

Some of the angular Lower-Greensand drift below Seal Chart and at Seal, and the angular flint-débris north of Child's Bridge, may possibly be of this date.

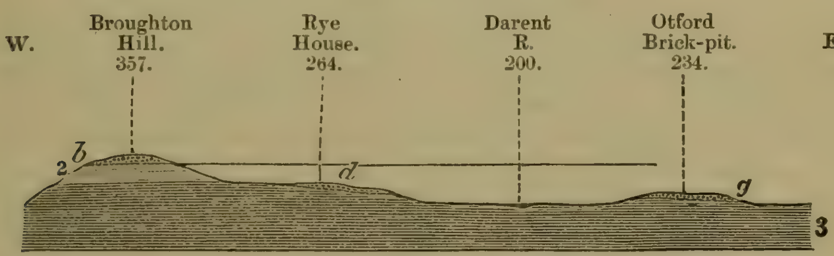
I should here observe that there is not infrequently, in this as in other districts, an apparent passage between one level of gravel and another, caused by a trail passing from the higher to the lower level, and so covering the slopes which separate the two drifts that they appear to form a continuous bed. This might easily lead to mistakes.

[Since writing the above, a cognate enquiry in which I have been engaged has led me to suspect another agency to which the angular patches of drift may be due. This has resulted in a drift which assumes so many phases that a revision of some portion of the lower drift-beds of this district may prove necessary, but it does not interfere with the definition of the higher-level valley and plateau drifts.]

## § 8. The Low-Level Valley-Gravels.

There are other drift-gravels in this valley, but they are more isolated and their correlation more uncertain. The most conspicuous outlier is the one between Otford and the "Bat and Ball" Station at Sevenoaks. It is one mile east of Broughton Hill, and on the opposite side of the Darent. The annexed section gives its position in relation to the several gravel-beds before described.

Fig. 10.—*Section from Dunton Green to the Otford and Sevenoaks Road.*




*b.* Gravel of the Limpsfield level.
*d.* Gravel of the Chevening level.
*g.* Low-level river-gravel.
2. Lower Chalk. 3. Gault.

Although so near, this gravel is very distinct from that on Broughton Hill or at Dunton Green. It is irregularly bedded, with veins of grey sandy clay, and consists in larger part (60 per cent.) of subangular fragments of Chert, Ragstone, and Ironstone from the Lower Greensand, with a lesser proportion of subangular

flints, and some Tertiary flint-pebbles. A few of the pieces of Chert are of the variety known as "Oldbury Stone." The sandy matrix is of Lower-Greensand origin. No organic remains and no Palæolithic implements have hitherto been found in this pit. The surface of the underlying Gault is nearly level.

The gravel has all the appearance of a river-drift formed at the junction of the east and west branches of the Darent Valley, and whether or not it is a stage newer than the Chevening and Dunton-Green gravel it would be difficult to say. The difference of level, though slight, the unstratified condition of one drift, and the rough bedding of the other, point to a difference of origin and time. The surface of the gravel at the Otford pit is slightly contorted as though by the action of river-ice, as at St. Acheul, in the valley of the Somme, though it is here less apparent and on a much smaller scale. I know of no similar bed in the western branch of the valley, unless it be connected with the small drift deposit of brick-earth and gravel at Froghole Farm near Chipstead. In the eastern branch, the small outlier at Child's Bridge * is of the same age.

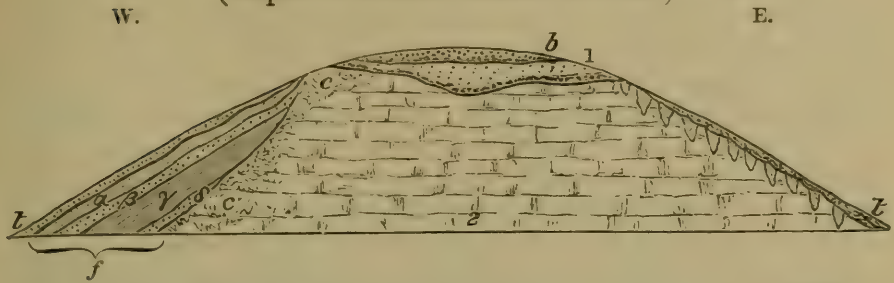
North of Otford, no beds of gravel are to be seen for some miles down the valley, but in laying a drain on the west side of the valley near the paper-mill at Shoreham a thin bed of sand and gravel, consisting of flints with worn fragments of Chert and Rag-stone, was discovered beneath the surface-soil. In this the tusk of a Mammoth was found, with traces of land- and fluviatile shells†. It was 30 feet above the level of the river; and at about the same level and under similar circumstances a tooth of the Mammoth was obtained at Eynsford. These are the only two instances in which organic remains have been found in the Valley of the Darent, though so common in the adjacent valleys of the Medway and Thames. A considerable spread of gravel on a low level is shown on the Geological-Survey maps in the valley between Lullingstone and Eynsford, but there are no pits or sections.

At the junction of the Darent with the Thames Valley, some sections of considerable interest were exposed on either side of Dartford during the making of the North-Kent Railway in 1842. On the Stone or east side, the line passed through a thick bed of gravel (15 to 20 feet), regularly bedded, and reposing upon a nearly level surface of Chalk (*ante*, p. 144). I am not aware that any fossils were found in it, and Palæolithic implements were then unknown and unsought for. It belongs to the great stream of gravel of the old Thames, but it shows the influence of the Darent-Valley stream in the large amount of Lower-Greensand débris there present.

On the west of Dartford there are two short cuttings between the Darent and the Cray, of considerable importance in their bearing on this enquiry. The one adjoining the Darent Valley, and at right angles to it, is as follows (fig. 11):—

* Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 274, 285.
† Geol. Mag. dec. iii. vol. vi. p. 113.

Fig. 11.—*Section on railway ¼ mile west of Dartford.*
(Depth of Section = about 30 feet.)




*t*. Trail of loam with flints and flint-pebbles ............... 1 to 2 feet
*b*. Ochreous flint-gravel ........................................ 3 „
*c*. Broken chalk. *c'*. Angular flint-rubble.
*f*. { *α*. Gravel composed chiefly of Tertiary pebbles ......
*β*. Yellow sand ................................................
*γ*. Grey clay ...................................................
*δ*. White sand with land- and freshwater shells ...... } 10 „
1. Thanet Sands ................................................ 4 to 5 „
2. Chalk, with a festooned surface beneath the trail on the east side of the cutting. *The indents are drawn too deep.*

The shells were *Pisidium amnicum*, *Valvata piscinalis*, *Pupa marginata*, and a *Succinea*. Some fragments of bones were, I believe, also met with. The bed *f* corresponds with the well-known bed at Erith, from which the late Mr. Grantham and Mr. F. Spurrell obtained so large a collection of Mammalian remains.

We have here a definite horizon with which to correlate several of the beds before described. There is little doubt that the bed with elephant-remains at Shoreham and Eynsford corresponds generally with *f*, fig. 11, and the height above the river of the bed of gravel at the Otford brick-pit (*g*, fig. 10) agrees so closely with the relative levels of the above that it affords grounds for placing it in the same zone. The gravel *b*, which belongs to the high-level gravels of the Thames Valley, is older than *f*, and so therefore is the Limpsfield gravel-bed with which I would correlate it.

This section also throws light upon a feature common in the Chalk districts of Kent and Surrey, and which has yet failed to meet with an explanation. I allude to that peculiar wavy breaking-up of the surface of the Chalk to the depth of 2 to 4 feet, in the form of closely-packed, small spherical pockets with concentric lines of clay and soil, which has been termed the "festooning of the Chalk."

On the western side of the cutting, the Low-level drift (*f*) abuts against a steep low cliff of Chalk, and there is no festooned surface, whereas on the eastern slope, where the Chalk has not been worn back in the same way, the whole length of the slope exhibits, under the thin covering of trail, the festooning as figured. In another railway section, rather nearer to Crayford, the same bed, *f*, again abuts against the Chalk, and overlies a mass of flint and Chalk rubble; and while under this bed the Chalk shows no festooning, that portion of the Chalk slope which rises above it, and extends to the top of the section, is strongly festooned.

It is therefore evident that the festooning took place before the undermining of the slope and deposition of *f*, but subsequently to the spread of the gravel *b*, or during the period intervening between the High-level gravels of Dartford and Limpsfield, and the Shoreham and Eynsford Mammaliferous drift—a period which corresponds with that of the Chevening drift; and if the Chevening drift is to be attributed to glacial agency, this festooning may be one of the effects of cold on the surface, either by repeated freezings and disintegration, or by the puddling of the ground caused by the passage of masses of snow and ice over the surface of the Chalk. It is a feature so common that it must be due to some very general cause—possibly to the same one that formed the Chalk-rubble described in the next section (§ 9).

It follows from the preceding considerations that there are in this district four distinct zones or levels of Drift, and that in three of these Palæolithic implements have been found, namely :—

1. That (*a*) of the High plateau on the Chalk hills, and of which the implements exhibit a distinct difference in type and workmanship from the other two. This is possibly of pre-Glacial or early Glacial age.

2. That (*b*) which accompanies an early stage of the existing river-courses, and includes the High-level gravels of the valleys (the "Hill group" of Ightham).

3. That (*e*) of a Lower-level valley drift. The implements found in this and the preceding zone, *b*, are very similar in character, and can only be regarded as variations of the same group *. They both belong to the so-called "post-Glacial" period.

No organic remains have hitherto been found in the older drift, and they only occur locally in a few places in the second, while they are common in the last.

### § 9. The Rubble on the Sides and in the Bed of the Valley.

Another feature connected with this valley, and very general in the Chalk districts of the South, is the débris of broken chalk and flints scattered over the slopes and at the base of the hills. Its origin is obscure. It has been referred to subaerial action and rainwash—terms which, though applicable in some instances, are too often used in default of a better. Both these terms imply surface-action and effects due to existing causes, and cannot therefore apply to any deposit due to anterior geological causes.

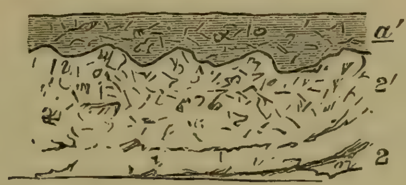
As the "Chalk- and flint-rubble" frequently forms the surface-soil, it might, without further investigation, be referred indifferently to one of the causes just named, did not the irregularity and absence of sorting of the materials militate against its being rainwash, while the occasional presence of materials foreign to the spot is an objection to local disintegration. But though the surface of the "Chalk- and flint-rubble" is often, or rather is more generally, bare, it is occasionally covered by a bed of red loam or clay with flints and

* The main difference seems to be one of size and proportion.

pebbles derived evidently from the Red Clay-with-flints, and from the Lower-Eocene strata on the adjacent hills. This red argillaceous rubble is certainly not rainwash, nor can it be the result of surface disintegration. At present, however, I am only concerned with the fact of its being a drift or covering which precludes us from assigning the Chalk-rubble which underlies it to such existing causes as rainwash or weathering.

Not being worked for any purpose, it is rarely that sections of these "rubbles" are to be seen. Of the few that have come under my notice in this valley, the following (fig. 12) is an example. It occurred in digging a pit about 10 to 12 feet deep for a reservoir in a field on the slope above Sepham Farm, near Otford.

Fig. 12.—*Section on Sepham Farm, on the lower slope of the Chalk hills.*




a′. Red argillaceous rubble with dispersed Chalk flints and Tertiary pebbles.
2′. Chalk-rubble of broken chalk and sharp angular flint-fragments in a chalk-paste, passing into—
2. Solid Chalk with layers of flint.

The two beds (*a′* and 2′) are perfectly distinct, and never pass one into the other; 2′, on the other hand, does not form a sharp line with the underlying Chalk, but graduates into it. The height of the ground is about 280 feet above O.D., and 90 feet above the level of the Darent. The Red rubble is easily recognized in the ploughed fields by its colour. But while this is local and only covers certain areas in the valleys intersecting the Red Clay-with-flints plateau, the white "Chalk- and flint-rubble" is more general *, passing under the Red rubble, as well as over the wider intervening spaces. In those valleys to which it is limited it rises to a considerable height on the slopes and descends to the bottom of the valley.

From the position and character of the White rubble, in which the Chalk forms a pulverized paste with dispersed subangular fragments of chalk, sharply angular flints—broken but otherwise unaltered—and occasionally some Tertiary flint-pebbles, and a few fragments of ironstone and chert from the Lower Greensand, it is, I think, not improbably Glacial waste connected with that stage of valley-erosion which preceded the drift *f*, and of which the festooning of the Chalk is a subordinate feature.

Just east of Otford, at the angle formed at the junction of the Holmesdale Valley with the pass of the Darent Valley through the

* 'Chalk- and flint-rubble' was said to underlie the Mammoth-gravel at Shoreham.

North Downs, a spur of Lower Chalk projects forward. It presents a compact even surface, merely covered by 1 foot of chalky soil, and free from either of the rubble-drifts. The line between the Chalk and the soil is perfectly sharp and clear. There is no passage from one to the other. The surface-layer has the characters of a wash—maybe a rainwash—the slope above being steep and abrupt. This surface is such as might have been produced by ice-action, though it is only by its rounded form and clean-swept surface that we can judge, for of ice-marks on a soft Chalk surface there can be none. This conjecture accords, however, with the supposition that the Chalk-rubble cannot be due to surface decomposition, for were it so it should exist here, whereas the position of the spur at the angle of the two valleys is that where the denuding action of the ice would be greatest, and the surface most likely to be swept bare.

### § 10. The Alluvium and the associated Neolithic Implements.

Of this last phase of the Darent Valley there is little to be said. A small breadth of alluvial clay spreads over the bottom of the valley (see Map, Pl. VII.), and levels the inequalities of the underlying drift. The greatest expanse of this alluvium is between Otford and Riverhead, but in general it is comparatively of little importance. The clay is of a brown colour, and occasionally slightly peaty, but there are no regular beds of peat, nor is the clay, which is from 3 to 8 feet thick, anywhere worked, and little is known of the underlying gravel and chalk débris. At Shoreham Mill the latter was found to be about 8 to 10 feet thick.

But although geologically unimportant, the large number of Neolithic flint implements found on the surface of the adjacent fields testify to the comparative density of the population during the prehistoric epoch. Flakes, celts, scrapers, cores, &c. are common on the Chalk slopes and lower grounds. They are mostly rude, weathered white, and iron-stained at the angles by the plough. Only a very few ground and polished specimens have been found; arrow-heads are scarce, but a few highly finished specimens have been met with. The district was evidently much frequented by Neolithic man, as it had been previously by Palæolithic man. This, however, is a subject for the archæologist.

### § 11. On the Chalk Escarpment within the Darent District.

Although the Darent district is of too limited extent to embrace all the phenomena connected with the structure and origin of the Chalk escarpment, it nevertheless presents a number sufficient to test the accuracy of the hypotheses that have been proposed in explanation of this moot problem, and to show how far the facts we have had to notice are in accordance with them. I do not, however, intend here to enter upon a full discussion of the subject, which is one that requires a wider field of observation, but merely to notice certain objections to both hypotheses that present themselves within the area of the Darent Valley.

Two hypotheses have been proposed to account for the formation of the escarpment surrounding the Wealden area. The one attributes its origin to marine action, and likens the long escarpment to Chalk cliffs surrounding an inland sea: the other refers it to subaerial action and a slow retrocession of the outcropping edges of the Chalk. The first of these hypotheses is now generally considered to be untenable, as no single one of the attendant phenomena is in accordance with such a derivation. There is not a trace of marine action within the Wealden area during the Quaternary period, and the escarpment is not a cliff in the ordinary acceptation of the word, for so far from there being a level shore-line at the base of the escarpment, such as a cliff necessarily presents, the line is in no instance level, but rises and falls alternately the whole length of the escarpment (see line *mn*, fig. 3, Pl. VI.), the difference of level between the higher and lower points amounting in places to as much as 300 feet, a difference impossible on a shore-line. The reader should, however, consult on the Chalk escarpment the writings of Mr. Whitaker, of Sir A. Ramsay *, and of Messrs. Le Neve Foster and Topley (see note, p. 126).

The second and more generally accepted hypothesis † is not so easy to disprove. It will, however, I think, be found incompatible with the phenomena exhibited in this district. I formerly showed that a large portion of the Chalk covering the Wealden area was, in early Tertiary times, planed down and levelled by marine action, forming what Ramsay has termed "a plain of marine denudation;" but I much doubt whether it affected more than a limited littoral area, and whether the Chalk was removed from the whole of the more central area. It is certain that the denudation extended beyond the North Downs, and probably to some distance to the south of the Lower-Greensand area ‡. It is also certain, as I afterwards showed, that both the Tertiary strata and the Chalk along the northern boundary of the Weald underwent a similar erosion during early Pliocene times §. In neither instance, however, is there any proof that the denudation reached far into the Weald, but, on the contrary, the absence in the first period of Lower-Greensand débris in the Tertiary strata, and in the second of Wealden débris, leads me to believe that much of the area remained almost untouched.

In any case, after the withdrawal of the Pliocene sea, and on the land being raised and exposed to atmospheric agencies, a process of weathering commenced, which led Ramsay, writing in reference to the formation of the Chalk Downs, to observe that "immense tracts of Chalk and Lower Greensand in the Weald and in the middle and west of England have been cut away by the slow process of gradual recession due to atmospheric influences, and thus it happens that

* Whitaker, Quart. Journ. Geol. Soc. vol. xxiii. (1867) p. 265; Ramsay's 'Physical Geology and Geography of Great Britain,' 5th ed. (1878) p. 338.
† See Ramsay, *op. cit.* pp. 336, 510, 532.
‡ Quart. Journ. Geol. Soc. vol. viii. (1852) p. 256.
§ *Ibid.* vol. xiv. (1858) p. 330.

their edges now form long escarpments, which are still receding in the direction of the dip of the strata, and therefore at right angles to the slope of the scarp" *.

That a plane surface of unequal resistance should suffer unequal wear from the effects of rain and weathering is not to be contested, but on the hypothesis that the escarpment of the North and South Downs is due to ordinary slow action of this description, we should assuredly expect to find in the valleys below them the harder and indestructible débris of the removed strata, such as the flints in the Chalk and those in the overlying Red Clay, and the pebbles of the Tertiary strata.

Sir A. Ramsay felt the difficulty, for he observes that "the absence of flints over nearly the whole of the Wealden area, excepting near the Downs, is explained by this hypothesis, *for the original marine denudation had removed all the Chalk, except near the margin* (see fig. 73), *long before the rivers had begun simultaneously to scoop out the valleys of the interior, and to cut the transverse valleys across the North and South Downs*" †. In the section referred to the Chalk is shown to extend no farther than the edge of the Lower-Greensand escarpment, a distance of four miles from the Chalk escarpment. But is not this limited range based on the very assumption of a fact which has to be proved?

Taking the range of the Chalk from Crossness in the centre of the Thames Valley, where its thickness is known, to the edge of the Chalk escarpment at Otford, a distance of 14 miles, we find it diminished from 650 ft. to 450 ft., a total reduction of 200 ft., or of $14\frac{1}{2}$ ft. per mile. At this rate the Chalk should have extended 31 miles beyond the escarpment, or, taking only the Chalk-with-flints, some miles (16 ?) less.

Within this area, if the Chalk had been worn back by ordinary subaerial agencies alone, we ought to find some evidences at the foot of the hills of the wreck of the Chalk with its massive layers of flints, of the pebble-beds of the Tertiary strata, and of the bed of Red Clay-with-flints (both of which latter may have extended farther than the Chalk-with-flints), in the manner represented by Ramsay in fig. 70, p. 336, of his work above referred to; but there is no bed nor any talus of that description. Mr. Topley, however, is of opinion that "we cannot expect to find any *direct evidence* that the escarpments have been formed and worn back by subaerial agencies," but considers that the whole features are such as can be readily explained by subaerial denudation, whilst all other agencies are inadequate to account for the work done ‡.

Nevertheless, if the hypothesis is to be accepted, some such direct evidence ought to be forthcoming, even if we assign a more restricted range southward to the Chalk and confine it to the limits assigned by Ramsay; or, at all events, the drift in the valleys within those limits should be in accordance with that hypothesis. On this point the sections in the Valley of the Darent offer a

* 'Physical Geology and Geography of Great Britain,' 5th edit. p. 351.
† *Op. cit.* p. 344.
‡ Mem. Geol. Survey, 'Geology of the Weald,' p. 300.

crucial test. Though the Gault elsewhere at the foot of the Chalk escarpment often shows a sprinkling of drift, there is no place where the character of that drift has been so well shown as in the sections on the line from Dunton Green to Westerham.

At first sight these sections might seem to corroborate the view of those who hold that the escarpment has been worn back by slow subaerial denudation, for, as I have shown (p. 149), traces of the Red Clay with its flints, together with flints from the Chalk and pebbles from the Lower Tertiaries, are there, though in very small quantity, and only in local patches.

But so far from possessing this uniformity and the special local characters in accordance with such an origin, the drift-beds in the valley present a marked diversity, while there are spaces free from any drift. If we take, for example, the section across the valley at Dunton Green, we find that instead of this uniform débris a chalk-and-flint rubble extends from the slope of the escarpment to Broughton Hill, which, on the other hand, is capped by a gravel of Chalk flints and Tertiary flint-pebbles, with Lower-Greensand débris brought from a distance; at Dunton Green there is the peculiar angular-flint drift with scarcely a trace of Lower-Greensand débris, while the Low-level drift in the valley beyond consists of mixed flints and Greensand débris.

On the rising ground (of Lower Greensand) on the side south of the valley the drift is composed almost entirely of local débris, and there is scarcely the trace of a flint (see Pl. VI. fig. 1). It is obvious, therefore, that here we have not simply a local drift of Chalk flints and Tertiary débris, left behind during a slow weathering and recession of the escarpment, but successive streams of drift-gravel, formed by erosion, and transported from other points higher up the valley. Of course, in a slow recession, the effects of springs, streams, and freshets are not to be overlooked; but it is not to be supposed that these would be of such a character as to remove or alter all the evidence of the primary cause, and until some of that evidence is forthcoming the hypothesis must, like that of the marine origin of the escarpment, fail, not only for want of proof, but also as against such evidence as we have.

Instead of a slow gradual recession, due only to atmospheric influences, in the direction of the dip of the strata, the evidence rather shows that, after the first predisposing causes, glacial agency was the great motor in developing the valleys, and, as a consequence, the escarpment; and that the denudation was afterwards further carried on in the same lines by strong river-action and weathering,—supplemented at times by renewed ice-action. It was, I conceive, by these more energetic agencies, aided by the influence of a heavy rainfall, and the issue of powerful springs on the face of the escarpment, that the escarpment was gradually pared back and brought into its present prominent relief.

[Other observations in connexion with the denudation of the Wealden area, and concerning the course and action of the rivers during its early stages, will be found in my paper "On the Southern Drift," in Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 166 *et seq.*]

## EXPLANATION OF PLATES.

### Plate VI.

Sections.—The levels are taken from the Ordnance Maps, but in order to make the sections clear the relations of heights to distances are made as 5 : 1, so that the gradient of the Plateau-Drift is considerably exaggerated.

Fig. 1. This section passes about $\frac{1}{2}$ mile west of Broughton Hill, which is, therefore, represented as in the distance, but the relative levels are maintained. Broke Farm lies a short distance back of the number 480. Snag Lane is 2 miles lower down the valley of the Cray than the point crossed here.

Fig. 2. Extends from Oldbury to Yaldham along the line of watershed (now removed in part) between the Darent and the Shode. Ash lies a little to the east of the line of section between South Ash and West Yoke. The brick-earth and gravel, *e*, with Mammalian remains and Palæolithic implements (⊙), north of Milton Street, lies a short distance east of the line of section, but on the level here represented.

Fig. 3. In this section it will be seen that the Lower Greensand débris (Southern Drift) and the Palæolithic implements (▽) are of frequent occurrence on the highest summits of the escarpment. The dotted line above *e* across the Valley of the Darent gives the level of the Limpsfield drift at the adjacent Broughton Hill. The dotted line *mn* follows the base-line of the escarpment—the summit-level at Limpsfield being near *l* and at Yaldham at *l′*.

### Plate VII.

Map.—This is based essentially on the Geological-Survey Maps, with the exception that the Drift-beds are altered and added to in accordance with the interpretation given to them in this paper. The angular gravel, *h*, should probably have greater extension. The Sundridge and Brastead gravels, of which I have never as yet been able to see a section, should possibly be referred to the same zone. It also covers more ground about Seal and below Seal Chart. The Southern Drift is taken as co-equal with the Red Clay-with-flints. The names of places generally indicate the position of their churches.

In the drawing of this map I have been much indebted to the kind assistance and suggestions of Mr. Topley.

### Plate VIII.

These sketches, made by Mr. W. S. Tomkin, represent some of the more common forms of the Plateau-Implements. Figs. 1 to 6 will be found described in the text, p. 134. Fig. 7 is an exceptionally good instance of the scratches or striæ, closely resembling glacial striæ, which are not infrequent on the brown-stained flints. In this case the large misshapen flint seems to have been trimmed at the edges so as to form a rude cutting instrument or adze.

In consequence of the uniform brown colour which spreads alike over the natural and the worked surfaces of the flints, independently of the original colour, the distinction between the two surfaces is rendered less apparent than is shown in the drawings, where the originally darker natural surfaces alone are shaded, while the colour on the worked edges is not rendered. Added to this the wear and abrasion which have affected the whole flint, including the trimmed parts, are not made sufficiently apparent. These parts, therefore, show more prominently than in the specimens themselves. The figures in Q. J. G. S. vol. xlv. pl. x. exhibit this feature better, though the general drawing is not so good.

## Discussion.

Mr. Topley referred to the importance of this paper as completing the history of the Darent Valley, and also as discussing questions of wider interest. He would not take up time by speaking upon the numerous matters in which he fully agreed with the Author, but would rather refer to a few points which still required consideration or as to which he was inclined to dissent from the Author's conclusions.

Many of the supposed implements from the Chalk plateau might reasonably excite suspicion, but some no doubt were artificial. He wished to know if there was any clear case of these occurring undoubtedly in place in these gravels; for the extremely high antiquity of any gravels in such positions was beyond question: it was clearly older than the excavation of the great Chalk valleys and of the present features of the Wealden area.

The high gravel at Limpsfield Common lies on the watershed, and therefore could not have been formed by the Darent in its present form. The Darent Valley probably once stretched farther to the west and south than now, having been robbed of its area by the recession of the higher tributaries of the Medway; but he was inclined to doubt if even this would explain the occurrence of so great a deposit at so high a point, and was rather disposed to think that the Limpsfield gravel itself had an origin independent of the present valley-system of the Darent. He fully agreed with the Author, however, in regarding the gravels lower down the Darent as river-gravels, largely made up from the waste of the higher and older bed.

Whilst admitting the evidence furnished for some kind of ice-action within the area, he could not follow the Author in attributing the escarpment to glacial action. He failed to see how ice could excavate the deep transverse valleys and cut back the escarpment at the same time, there being no doubt that these two very different kinds of denudation proceeded simultaneously. He showed that glaciation tends to destroy escarpments. Existing escarpments in glaciated areas are such as were too bold to be destroyed, or, if small, are such as may have been developed since the glaciation. Lastly, escarpments are universally distributed over the world, whilst glaciation has influenced only parts of it.

Prof. Le Neve Foster wished to say a few words respecting the denudation of the Weald, having studied that subject carefully with his friend Mr. Topley some six or seven-and-twenty years ago. He did not find his old views shaken by the paper which he had just heard, and was still of opinion that the formation of the Chalk escarpment was due in the main to rain and rivers. Mr. Topley had forestalled him in one remark, viz. that any theory accounting for the Chalk escarpment should also account for escarpments elsewhere. If, by glacial action, Prof. Prestwich meant that glaciers had helped to carve out the Chalk escarpment, ought there not to be some evidence of the fact in the shape of scratched stones? He

had not learnt from the paper that any scratched stones had been discovered. Though the soft chalk, clays, and sands of the district would not permanently retain scratches, yet there are flints and ironstones capable of preserving striations. On the other hand, local ice-action on a small scale was admitted, and Mr. Topley and he had resorted to that explanation to account for the very sharp bending of some beds of gravel near Tonbridge; but this was a very different thing from allowing that the origin of the Chalk escarpment is largely due to ice-action.

Mr. De B. Crawshay had recently discovered the Southern Drift on the top of Botley Hill, near Titsey, the highest point (877 feet) on the North Downs, and had there obtained five rude implements. He had also found rude implements on the Tatsfield Firs at 820 feet, thereby proving the four highest patches in that locality to yield implements. He remarked upon the Betsom-Hill patch at 750 to 790 feet being on the south side of the escarpment, thereby differing from all the others. With regard to implements *in situ*, he observed that Mr. B. Harrison had found a flake on the side of a pond at Ash, below the level of the surrounding plain. He hoped to open sections in the course of the year, and would be very pleased if Fellows of the Society would come and see them. Many of the flints were scratched, but he did not advance them as glacial striations, and would leave the Author to deal with them.

The President, after alluding to the Author's researches many years ago, which threw so much light on the origin of the river-terraces and topography of the South-east of England, and revealed to geologists important evidence of a former extremely cold climate in that region, asked for information regarding the nature and operation of the glacial action to which it was proposed to refer the formation of the Chalk escarpment. He confessed himself unable to realize how any operation of ice could have played a material part in the sculpture of that part of our topography. At the same time, he thought that geologists made a great mistake who looked in the Southern Counties for any such traces of ice-action as they were familiar with farther north. There was assuredly no ice-sheet in the south of the island; the Boulder-clay and scratched stones may be entirely absent, nor could the speaker see any satisfactory evidence of floating ice. Yet there could be no doubt that thoroughly glacial conditions did spread over south-eastern England, giving rise, however, to a different class of results from those that attended the more Arctic glaciation farther north. He reminded the Fellows of the suggestive paper communicated to the Society a few years ago by Mr. Clement Reid, which showed how a period of intense cold might be inferred to have prevailed along the South Downs, though that ground is quite bare of anything in the nature of true "Drift."

The Author, in reply to the comments on the paper, admitted that it was very desirable that plateau-implements should be found *in situ* in the drift, but the fact that there were no pits and that excavations were rare in the plateau-drifts accounted

LATIVE LEVTS,

GROUPS O

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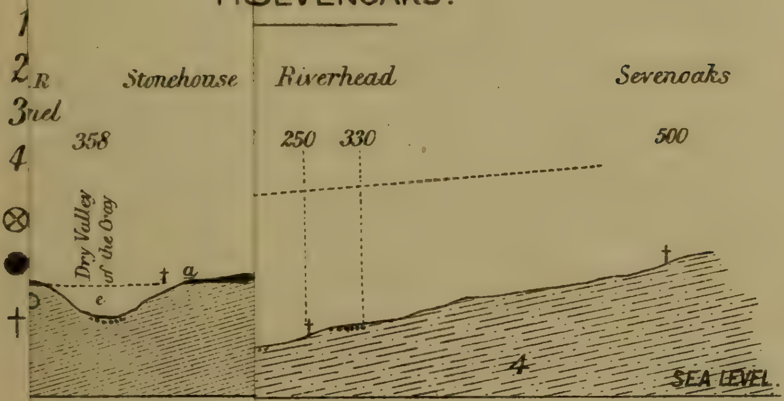


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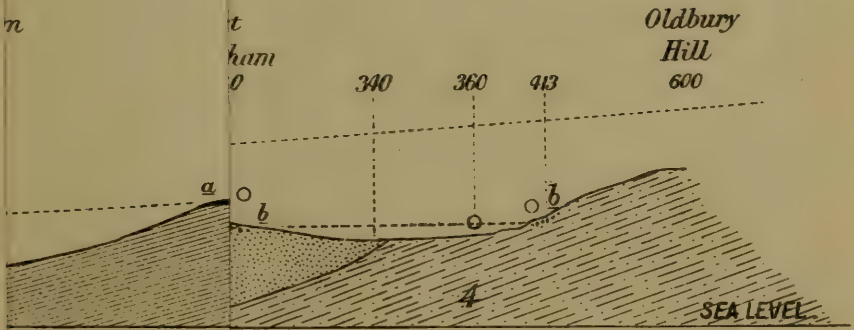


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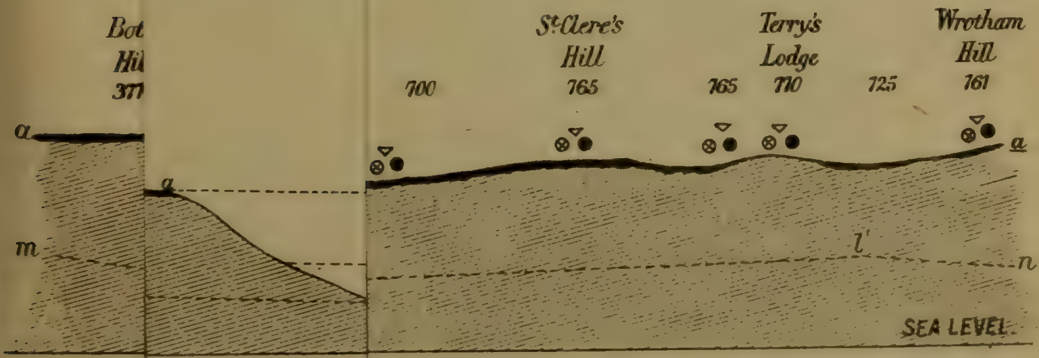


# Diagram-Sections showing the Relative Levels of the Plateau- and Valley-Drifts, and of the Three Groups of Palæolithic Implements.

## Explanation.

1. *Tertiary Strata.*
2. *Chalk.*
3. *Upper Greensand and Gault.*
4. *Lower Greensand.*

a. *Red Clay with Flints.*
b. *Upper Valley-Gravel.*
d. *Chevening and Dunton-Green Gravel.*
e. *Low-level Valley Gravels.*

⊗ *Stained Flints.*
● *Chert & Ragstone Fragments.*
† *Localities.*

▽ *Implements of the Plateau type.*
○ *Implements of the High-level Group.*
⊙ *Implements of the Low-level Group.*

## Scale.

*Horizontal* ............ 1 inch = 1 mile.
*Vertical* ............ 1/10 inch = 100 feet.

Fig. 1. Section from the upper part of the Cray Valley to Sevenoaks.

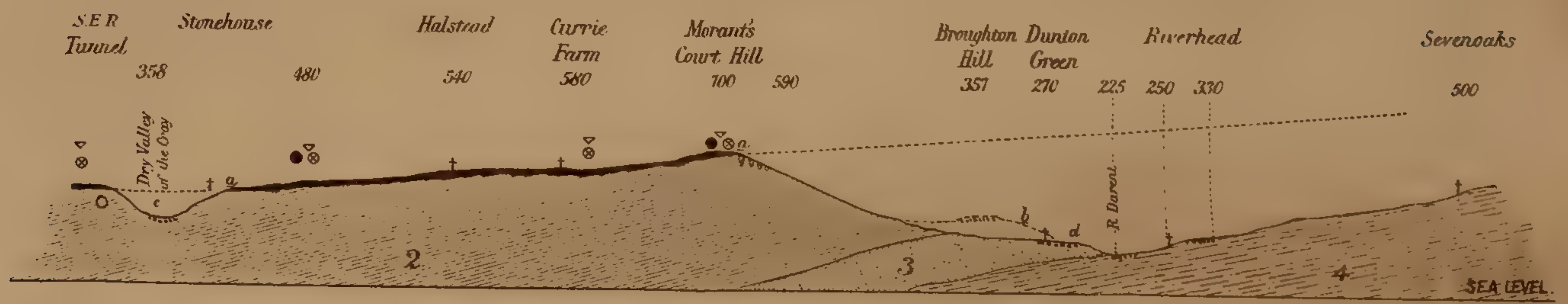



Fig. 2. Section from the Thames to Oldbury Hill near Ightham.

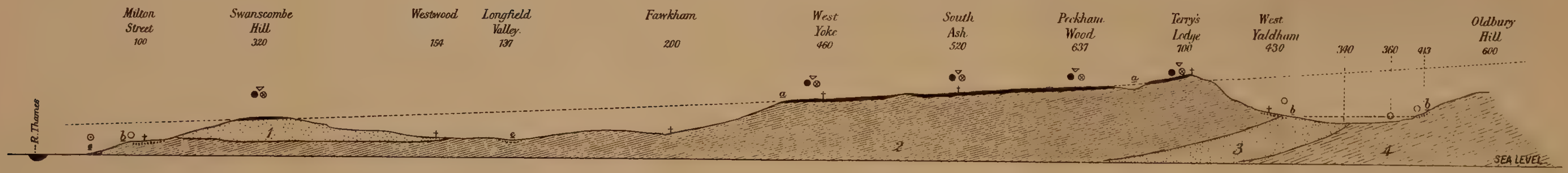
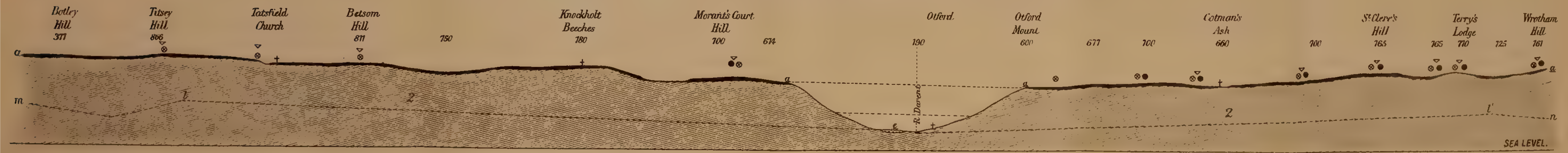
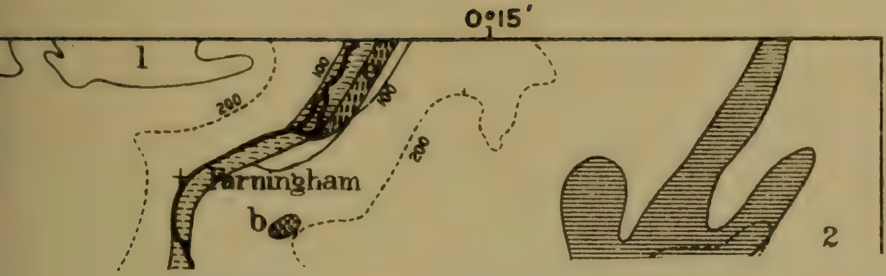



Fig. 3. Section along the Crest of the Chalk Escarpment from Limpsfield to Ightham.

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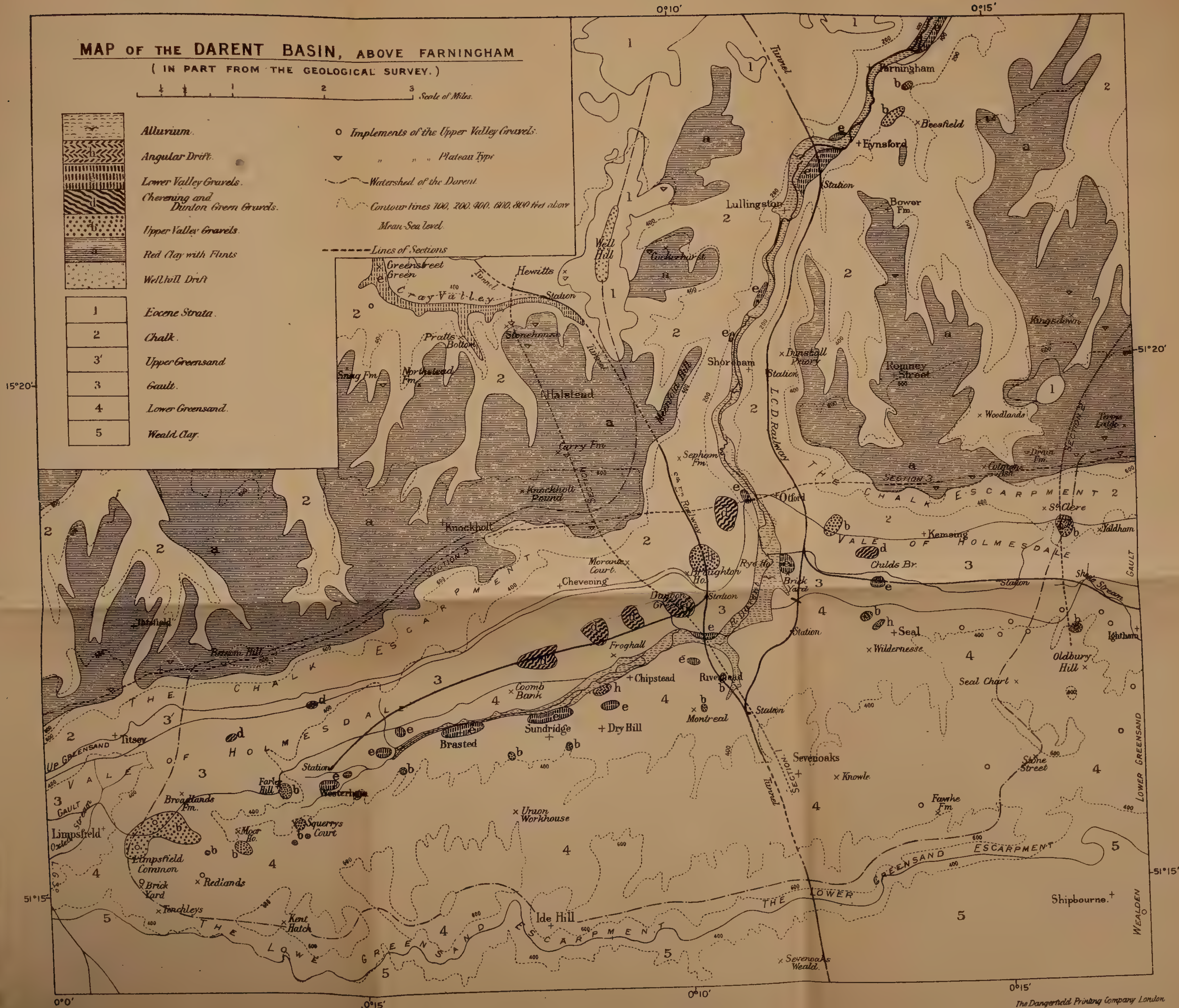



The Dangerfield Printing Company London.

Fig. 3. (110). Fig. 1. (150). Fig. 4. (112). Fig. 2. (406).

Fig. 7. Fig. 5. (57). Fig. 6 (53).

W. S. Tomkin del. Mintern Bros. lith.

FLINT IMPLEMENTS OF THE CHALK PLATEAU.

*Type Specimens ¾ natural size.*

for the search being limited to the surface*. These implements were, however, always found in close association with those drift-beds, and confined to the area over which they spread. These are never met with in the intervening valleys, except an occasional derived specimen in the newer drifts. Besides this, the colour and incrustation of the specimens show that they have been embedded in a surface-drift, which, with others, has suffered denudation, and it is probable that a large number of the specimens have been brought to the surface on which they are now found in course of working the land.

With respect to the Limpsfield gravel, it certainly wanted some of the characters of a river-drift, but ice and snow may have had a good deal to do with its lodgment. It is evident also that it has been derived from the Tertiary outliers on the adjacent Chalk escarpment 300 to 400 feet above Limpsfield Common, whence the fall would be exceptionally rapid. At the same time, the Limpsfield gravel assumes much more the character of a river-gravel as it descends the valley, in consequence of receiving tributary streams and acquiring greater water-power and deeper waters.

Respecting the brick-earth and the Chevening gravel, the Author pointed out that the disturbed condition of the former could be best explained by floating ice, and of the latter by a covering of ice and snow. That there should be an absence of striated surfaces and scratched stones was no more than might be expected, considering the want of hard rocks. Other evidence would, however, be found in the paper, which, from its length, he had found it necessary to omit in reading. There was certainly an appearance of striæ on some of the implements and older flints, but whether that arose from ice-action or from the rubbing and knocking about they received in the old drift-streams he would not at present like to pronounce.

The formation of the Chalk escarpment presented great difficulties. In the North of England, where the great ice-sheet passed over high hills, the escarpments would no doubt suffer defacement, but here the character of the ice-action would be different. The Author did not suppose that the great northern ice-sheet extended over this area. A southern central ice-area may then have existed in the Wealden highlands, and the ice and snow in these valleys have been local. The height of the glacial period preceded the Limpsfield gravel, and the W. and E. and the S. and N. directions of the flows were the result of different physiographical conditions at different periods.

The Author then expressed his obligations to the three gentlemen who had so greatly assisted him by their researches in the field, the results of which were to be seen in the large collection of Flint Implements exhibited.

* I have now seen the fine specimen mentioned on p. 133. It is 6 inches long by 3¾ in. wide, very flat and round-pointed, and shows no wear. It more resembles one of the large St. Acheul types. It was found on the top of the soil last thrown out of the hole.

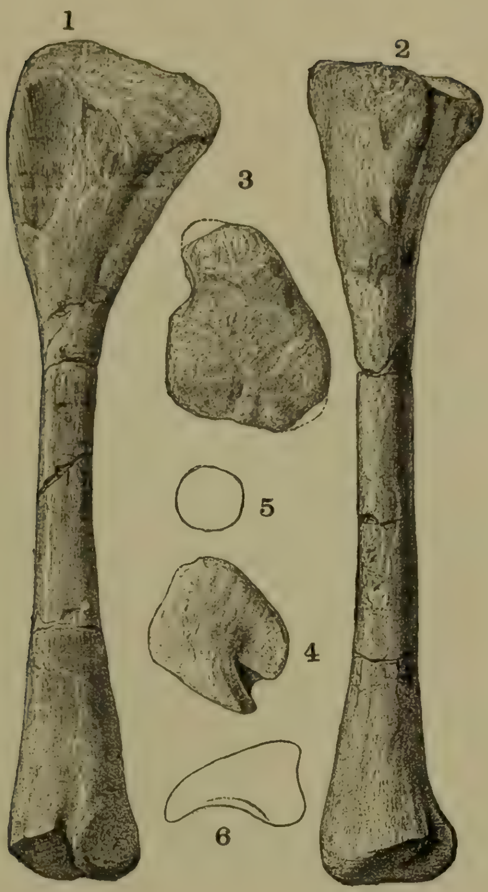
12. *On* Agrosaurus Macgillivrayi (*Seeley*), *a* Saurischian Reptile * *from the* N.E. Coast *of* Australia. By Professor H. G. Seeley, F.R.S., F.G.S. (Read January 21, 1891.)

In July 1879 the Geological Department of the British Museum obtained by purchase from Mr. E. Charlesworth some fossil bones, which were dispersed at the sale of the collection of Mr. S. L. Waring, F.G.S., of Norwood, then recently deceased. They are labelled, in a small, delicate handwriting, "'Fly,' 1844. Jn. Macgillivray, from the N.E. coast of Australia." I believe this to indicate that the specimens were collected by Mr. Macgillivray during the voyage of the 'Fly,' from some locality which was then unnamed. The bones were placed in the Mammal Gallery, where they have since remained. They comprise a complete left tibia, a less perfect proximal end of the corresponding right tibia, a fragment which I regard as a portion of a fibula, attached to matrix, which besides other fragments of bone contains two laterally compressed claw-phalanges. There is necessarily no direct evidence of their geological age. But as they indicate a new Saurischian reptile, which has its nearest known allies in the lower Secondary rocks of Europe and the Trias of South Africa, it is not improbable that the animal belongs to the Lower Oolites or Trias. I have not noticed any reference to the specimens by Professor Jukes in the "Voyage of the 'Fly'" or in his other books and papers, or in the writings of Mr. Macgillivray.

The left tibia (figs. 1, 2) is about 20 cm. in extreme length, with the usual sub-triangular flattened proximal articular surface. That surface is nearly 5 cm. deep by 4 cm. wide posteriorly, and is flattened on the hinder and fibular borders, which are inclined at a right angle, and convex on the antero-internal contour, so that a distinct thick anterior crest is defined without obliterating the right-angled triangle form. The articular surface is slightly inclined towards the posterior and fibular borders, partly because there is a small patelloid convexity above the pre-cnemial crest, then a transverse concavity, behind which is the larger part of the articulation, consisting of two areas which correspond to condyles. These surfaces are divided by a shallow groove, and the larger condyle was on the external border. The posterior angles of these condylar surfaces are rounded and prolonged backward beyond the shaft, and there is a slight concavity between them.

The proximal end of the bone is expanded as compared with the unusually slender sub-cylindrical shaft, which is 12 millim. in diameter. The anterior internal surface, though flattened, is gently convex, and it rounds into the posterior surface of the bone, as well as on to the strong anterior convex ridge of the pre-cnemial crest, which is prolonged down the shaft for about 6 cm. with a gently convex

* See Proc. Roy. Soc. vol. xliii. p. 165, and Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 79.




EXPLANATION OF FIGURES.

*Agrosaurus Macgillivrayi* (Seeley).

½ natural size.

Fig. 1. Left tibia—fibular aspect, showing expansion of the ends of the bones.

Fig. 2. Left tibia—anterior aspect, with lateral notch for the astragalus.

Fig. 3. Proximal articulation, showing impress of condyles of femur.

Fig. 4. Distal articulation, showing distinctive quadrate form and attachment for astragalus.

Fig. 5. Section of shaft, showing its cylindrical form.

Fig. 6. Claw phalange.

contour. The width proximally of the antero-internal surface is about 5 cm., but it narrows rapidly. The posterior contour of the shaft is concave.

The surface of the bone at the proximal end is moderately concave, with a slight vertical channel for the fibula towards the external crest. This is augmented by crushing, in the left tibia, but the imperfect proximal end of the right tibia shows no *post-mortem* compression.

The slender portion of the shaft includes more than its middle third, and is more attenuated than in any Saurischian hitherto figured. Its section is ovate, and the bone appears to be thin and hollow.

The distal end expands gradually, so that there is no point in which it is sharply defined from the shaft; it is about half as deep as the proximal end. The articular surface is more quadrate than the distal end of any Saurischian tibia figured, with the exception of *Dimodosaurus poligniensis*, in which the proportions are similar. It is 3 cm. wide, and measures rather more in depth, with two pairs of sides nearly parallel, though the lateral borders converge a little forward. A deep notch indents the anterior margin in the middle, and marks a division of the basal surface which descends on the fibular side like a broad talon and indicates a corresponding modification of the astragalus. I infer from the quadrate shape of the articulation that the distal end of the fibula was carried external to the tibia, and not in front of it as in Ornithischia, which have the distal end of the tibia expanded transversely. The somewhat saddle-shaped articular surface is clean, and gives no indication of close union with the astragalus.

Another fragment may be the distal end of the fibula; it is less than 5 cm. long, with a slender shaft 1 cm. in diameter as preserved. The articular surface is oblique, flattened, and measures 2·5 cm. in width by 1·8 cm. in depth; it is convex on the tibial side, and less convex externally.

A fracture in the matrix displays two claws, which are flattened and appear to be compressed from side to side. They are of the type which is usual in carnivorous reptiles. The larger of them is 2·5 cm. long and 1·8 cm. deep at the slightly concave articular border: the contour of the bone is convex above and concave below. The smaller claw is more slender; it is 2 cm. long, and 1·3 cm. deep at the posterior articulation.

The distinctive character which determines the affinities of the fossil is the distal end of the tibia. It shows an ordinal resemblance with *Pœkilopleuron* and *Cetiosaurus*, but with *Dimodosaurus* from the top of the Keuper its resemblance is so close that the two must be regarded as nearly allied. I consider the fossil now described as generically distinct from *Massospondylus* and all known types, and defined by its slender shaft, by the enlarged proximal end which curves backward, by the slight development of the cnemial crest, by the uniform increase in size of the distal end, and finally by the moderate excavation of the distal articulation on the inner side. The remains indicate an animal about as large as a sheep.

## 13. *On* SAURODESMUS ROBERTSONI (*Seeley*), *a* CROCODILIAN REPTILE *from the* RHÆTIC *of* LINKSFIELD, *in* ELGIN. By Professor H. G. SEELEY, F.R.S., F.G.S. (Read January 21, 1891.)

LINKSFIELD is north of Elgin and west of the River Lossie. The locality was fully described by Professor Judd, F.R.S., in 1873 *, and the strata, previously regarded as Lias and Wealden, were interpreted as a large boulder of Rhætic beds in Boulder-clay †. A number of freshwater shells occur in these beds, associated with land plants, marine invertebrata, fishes, and reptiles; but very few of the species are identical with those found in other European localities. And, although there is not much room for doubt as to the age, I could have wished the evidence stronger in determining the horizon of the interesting specimen now described, which was found by Mr. A. Robertson, of Inverugie. It appears to be an isolated bone, first noticed nearly fifty years ago by Sir R. Owen in his second report to the British Association on British Fossil Reptiles. "I have been favoured by Mr. Robertson of Elgin with the examination of a Chelonian femur 4½ inches in length from a stratum at Linksfield in which remains of *Plesiosaurus* and *Hybodus* occur; and this femur, though not identical in form with that of any *Trionyx* with which I could compare it, yet resembles the modifications of the bone in that genus more closely than in Tortoises, Emydians, or Turtles." This guarded determination has sometimes been read as referring the specimen to *Trionyx*, but it amounts to no more than a statement that the bone is a femur, and probably Chelonian. It was figured in 1842 by Mr. Patrick Duff in his 'Geology of Moray,' pl. v. fig. 10. At that time only the dorsal aspect was seen. It was acquired by the British Museum in 1854, by purchase, from a sale at Stevens's, and registered by the late W. Davies as "? humerus of a ? Chelonian" ‡. In 1889 it was removed from the shelly matrix, so as to expose the ventral aspect of the bone. The latest reference to it is in the B. M. Catalogue of Fossil Reptiles and Amphibia, pt. iii. (1889), p. 223, where Mr. R. Lydekker places it after the remains of *Chelytherium* with the following description:—"The imperfect right humerus or femur of a Chelonian, perhaps referable to this or an allied form .... The head is wanting, and there is no distal groove or foramen. The specimen differs very markedly from the corresponding bone in any existing type." I am not aware of evidence which would associate the specimen with *Chelytherium*, and the association is not discussed. Mr. Lydekker's cautious determination amounts to no more than a belief that, while the

* Quart. Journ. Geol. Soc. vol. xxix. pp. 135–138.

† The Rev. Dr. Gordon informs me that he has seen glacial markings on the rock beneath this boulder.

‡ In an article on the Dinosauria in the 'Popular Science Review' for Oct. 1879, p. 46, I referred it with doubt to the Dinosauria.

bone is Chelonian, it cannot be referred to an existing type, and may be either a humerus or a femur.

There is in the mutilated proximal end of the bone some resemblance to a mammalian femur, such as that which I described from Stonesfield *, but the distal end of the bone forbids a comparison. And it is as certainly not the femur of any reptile. I am not familiar with any Chelonian in which the femur closely resembles the humerus. The bone is, I submit, a right humerus, but the characters have not hitherto been enunciated which would refer the bone to the Chelonia.

The characters which suggest Chelonian affinities have little value in classification. They are limited to the general form of the bone. The proximal end is expanded, with a saddle-shaped ventral surface, but this condition occurs in Ornithosaurs, in *Hyperodapedon*, and many extinct genera of reptiles. The distal end and the articular head of the bone appear both to be in the same plane, so that there is no twist in the shaft; but since the head is not preserved, it is not impossible that it may have formed an angle with the distal articulation.

I am indebted to Mr. Boulenger for the opportunity of examining bones of recent Chelonia in the British Museum, but I have found no evidence to sustain the Chelonian hypothesis, nor any closer resemblance than is seen in the right humerus of the genus *Hardella*.

Among the characters which I believe to constitute differences from Chelonians are (1) the cellular medullary cavity in the shaft of the bone, which is filled with calcite; for I am not aware that the humerus is hollow in any Chelonian; (2) the straight shaft is unparalleled in any Chelonians in which an approximate comparison could be made, for they have the superior contour convex, and the infero-posterior contour concave; (3) the remarkably open concave curve between the radial and ulnar crests is not paralleled in Chelonians, which have the more or less lamellar, sub-triangular, radial crest close to the head and reflected downward; (4) the radial crest is distinct from the head of the bone, does not extend so far proximally, and is relatively small, as in no Chelonian; (5) the slight development of the ulnar crest, the rough muscular attachment along its extent, and its convex contour in length are unknown among Chelonians; (6) the thickness of the ridge by which the shaft appears to have united with the articular head in the fossil is greater than among Chelonians, and it is possible that the shaft had an appreciable extension proximally beyond the fracture which limits its preservation; (7) the transverse curved ridges on the ventral side of the head from the radial process to the ulnar crest are distinct in their divergence from the not dissimilar ridges sometimes seen on the Chelonian humerus; (8) the distal end of the shaft is unlike Chelonians in the great transverse extent, in the flattening of the ulnar side of the bone, which is concave in length, in the compression of the

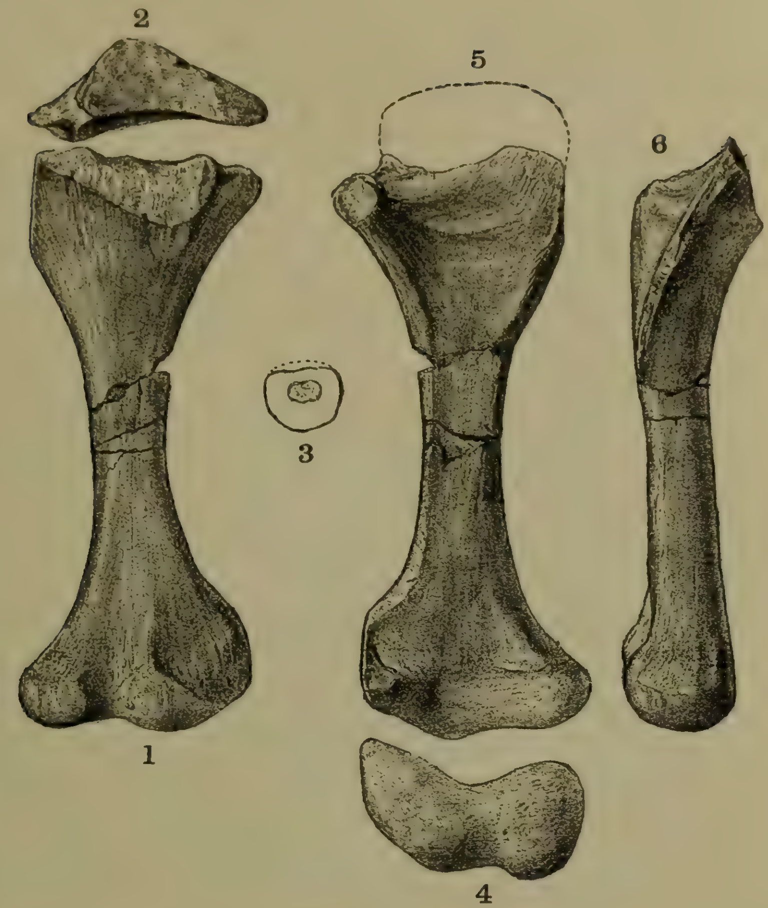
* Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 456.

radial side of the bone above the articulation to a sharp edge, which makes the longitudinal contour convex on that side at the distal end, and in the dissimilar form of the distal articular surface with its well ossified detail and definition. Even disregarding the absence from the fossil of a radial groove or perforation, the characters enumerated seem to me to outweigh the slight resemblances to Chelonians which it seems to present, and it would follow that there is practically no evidence of value in favour of the Chelonian nature of the fossil.

At first sight the bone (figs. 1–6) is not very like the humerus of a Crocodile, yet its affinities with the Crocodilia are more important. Careful consideration of the radial process in the fossil shows that its inner prolongation is a sharp almost knife-edge, as in Crocodiles, and that the proximal articular part of the bone prolonged the shaft beyond the radial process in a way only paralleled among Crocodiles. On the other hand, the radial crest is never reflexed forward so much in existing Crocodiles, and there is no Crocodile in which the ulnar border is compressed to a sharp muscular edge, though there is, perhaps, a faint suggestion of such a ridge in a proximal angle of the ulnar tuberosity; and in Gavials, some recent species of *Crocodilus*, and some fossil Crocodiles like *Crocodilus Hastingiæ*, the character is slightly marked.

The bone as a whole is much more expanded at both ends than in Crocodiles, and is even straighter, but the distal articulation is essentially the same in plan, with like details of condylar structure and a like compression of the bone on the radial side, though the ridge in the living types is very slight compared with its development in this fossil. These are, however, homologous characters, and Crocodiles have the limb-bones hollow; so that, as the indications from the proximal and distal ends and from the internal structure all point to the same result, it may be concluded that the Linksfield fossil indicated a primitive Crocodilian stock; and that the intensified characters which it shows are feebly preserved in its surviving representatives. The chief differences from Crocodiles are that the radial crest is directed more forward and less downward; that the ulnar side is sharply compressed, ends in a muscular ridge, and has a convex curve; that the shaft is straighter; and that the distal end is relatively wider, with its radial border much more compressed.

In Lizards there are some approximations in these points which are worthy of remark. The extremities of the bone are more expanded transversely than among Crocodiles, but then the shaft is twisted. Both the radial border at the distal end and the ulnar border towards the proximal end are compressed in Lizards, but then the distal end has enormous articular condyles equally unlike those of the Linksfield fossil and Crocodiles. The concavity below the head of the humerus is more open transversely in Lizards, but then a strong rounded ridge connects the radial crest with the articular head. In no respect, however, either in characters of the proximal or distal end, can Lizards be said to approach so near to the fossil as do Crocodiles. Nevertheless, there may be a tendency




## EXPLANATION OF FIGURES.

*Saurodesmus Robertsoni* (Seeley).

$\frac{3}{4}$ natural size.

Fig. 1. Dorsal aspect of right humerus, showing fracture of head of the bone.

Fig. 2. Outline of the proximal end of the bone, showing the relation of the radial crest to the shaft.

Fig. 3. Transverse section of the middle of the shaft, showing cancellous tissue.

Fig. 4. Outline of the distal articular end of the bone, showing form of condyles.

Fig. 5. Ventral aspect of the bone, with an approximate restoration of the proximal end.

Fig. 6. Posterior lateral aspect of the bone, showing the straight shaft, the curvature of its extremities, and the condition of the ulnar margin.

towards a generalized Lacertilian type, in so far as the characters are not Crocodilian, which is especially shown in the compressed distal radial margin.

The Trias of Elgin has already yielded *Telerpeton*, *Hyperodapedon*, and *Stagonolepis*, and the fossil is well distinguished from these. It is somewhat smaller than *Hyperodapedon*, which has the proximal end of the bone greatly expanded and concave, though less expanded than in *Stagonolepis*, but in neither genus is there the same resemblance to a Crocodilian type which is seen in the fossil under review. Among the extinct Orders it is in some ally of the Ornithosaurs that an approximation to the Linksfield type might be expected, for it is only in the humerus of the Pterodactylia that a close general resemblance to the fossil is found in those distal characters in which it varies from Crocodiles.

As preserved, the bone is 8·2 cm. long, and when perfect may have been from 1 to 2 cm. longer. At the fracture it is 3·5 cm. wide, and the bone is 1 cm. thick in the middle, where a muscular impression marks the large angle made with the ulnar and radial sides of the head. The middle of the shaft, which is nearly cylindrical, is 1·1 cm. wide. The distal end is 3·2 cm. wide. The articulation ascends the superior surface a little on two moderate ridges with a concavity between them. It is about 1·5 cm. thick on the ulnar side, and thinner on the radial side, the two parts being defined by the anterior and posterior concavities. These differ from the corresponding constrictions in the humerus of Crocodiles in that the depression in front is much narrower, while the inferior concavity is much wider. The form of the distal articulation indicates, I think, that the bones of the forearm were placed as in Crocodiles, and not as in Lizards or Anomodonts.

The compressed ulnar margin (supposing it to be unbroken), with a muscular attachment at its edge, would constitute an ordinal difference from existing reptiles. The fossil, if grouped with the Crocodilia, belongs to a suborder hitherto unknown, and defined by a combination of Crocodilian and Lacertilian characters which is not Saurischian.

### Discussion on the above two Papers.

Mr. Lydekker agreed with the Author in regarding the Australian tibia as that of a Dinosaur, but asked how it was generically distinguished from *Dimodosaurus* or *Massospondylus*. He was glad that the Author termed the bone from Elgin a somewhat unsatisfactory specimen ; in the speaker's opinion it was not worthy of being made the type of a genus. He differed from the Author in regarding the bone as being solid, and expressed his belief that although it might belong to a Rhynchocephalian or an extremely generalized Chelonian, it was certainly not Crocodilian, in any accepted sense of that term. He further enquired the Author's meaning in using the expression "Lacertilian affinities" in an apparently loose way. He concluded by protesting against the use of the term "Saurischia" for the typical Dinosauria. It was perfectly permissible to divide the Dinosauria

into two orders, but if this was done the original name must be retained for the typical forms. An analogous instance occurs in the separation by some writers of the Lemuroidea from the Primates, the latter being retained for the typical members of the order. Any other course would be unjustifiable.

The AUTHOR thought that if Mr. Lydekker visited Paris and sought the aid of Prof. Gaudry in making comparisons, he might learn the nature of *Dimodosaurus* and the relation of the Australian fossil now described to that type and its allies. He used the term "Saurischia" rather than "Dinosauria" in defining the position of this animal, because new ideas in classification needed new names for their adequate expression. It might be that the groups Ornithischia and Saurischia were provisional, for there were indications of a third group which could not be defined as yet. He thought there could be no more justification for the proposal to restrict the name "Dinosauria" to one of these groups than there would be to restrict the term "Mammalia" to the Monotremata or Marsupialia.

With regard to the Linksfield fossil, he had carefully compared it with every available specimen in the British Museum without finding evidence of near affinity with the Chelonia, though without doubt as to its osteological identification. This was the first necessity in making a determination of the bone. As Mr. Lydekker had been unable to determine whether the bone was a humerus or a femur, he did not know how it was possible for him to have arrived at any reference of it to the Chelonia or any other group. But when the form of the distal end was appreciated as fixing its place in the skeleton, it followed that only in Crocodiles and Ornithosaurs could any parallel be found to the characters of the proximal end, so as to bring it into harmony with the distal end of the bone. He fully admitted the difficulty in restoring the head of the bone in a new type of animal.

## 14. NOTES *on* ROCK-SPECIMENS *collected by* W. GOWLAND, Esq., A.R.S.M., F.I.C., F.C.S., *in* KOREA *. By THOS. H. HOLLAND, Esq., F.G.S., A.N.S.S., of the Geological Survey of India, late Berkeley Fellow of the Owens College. (Read November 12, 1890.)

(Communicated by Prof. JOHN W. JUDD, F.R.S.)

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I. Literature.
II. Introduction.
III. Igneous Rocks.
(1) Acid.
(2) Intermediate.
(3) Basic.
IV. Metamorphic Rocks.
V. Sedimentary Rocks.
VI. Summary.
VII. Appendix.


### I. LITERATURE.


1704. A Collection of Voyages and Travels. London. Vol. iv. pp. 623–632.

1818. Account of a Voyage of Discovery to the West Coast of Corea and the Great Loo-Choo Island. Captain Basil Hall. London. Pp. 1–57. Appendix, p. cxxi *et seq.*

1819. Voyage of H.M.S. 'Alceste.' John McLeod, M.D. Third Edition. London.

1834. Journal of Three Voyages along the Coast of China. Rev. Charles Gutzlaff. Third Edition. London. Pp. 227–249.

1873–74. China-Sea Directory.

1881. "Notes on the Geology of the Corean Archipelago," Nature, vol. xxiii. p. 417.

1886. "Geologische Skizze von Korea." Dr. C. Gottsche. Sitzungsberichte k. Akad. Wissensch. Berlin, vol. xxxvi. p. 857.

1886. "Beiträge zur Petrographie von Korea." Prof. J. Roth. *Ibid.* p. 875.


### II. INTRODUCTION †.

Although his visit in 1884 was primarily intended for purposes of archæological research, Mr. Gowland has succeeded, under considerable difficulties from the ill-concealed hostility of the natives,

* Mr. Gowland has kindly supplied me with the spelling of the names as adopted in the system of transliteration employed by Satow, Aston, and Chamberlain.

† In studying Mr. Gowland's collection of rock-specimens I have been greatly assisted by the maps and information he has so readily supplied. I would like to take this opportunity also of acknowledging my great indebtedness to Professor J. W. Judd, F.R.S., for facilities of study and kindly direction in the Geological-Research Laboratory of the Normal School (now Royal College) of Science, and to Professor W. Boyd Dawkins, F.R.S., for kindly placing at my disposal the use of the Geological Laboratories of the Owens College.

in collecting numerous specimens, and in making important observations on the geological structure of the interior of Korea.

Mr. Gowland traversed the country from Söul, the capital, to Fusan, on the south-east coast—the route thus roughly following up the basin of the Han River to the watershed (which forms a natural line of boundary between the provinces of Chhung-chhöng and Kyöng-sang), and then from the pass near Mungyong, following the course of the Naktong River to its estuary on the south-east coast.

The topography of the part of Korea thus crossed may be roughly ascertained from the list of aneroid-readings made by Mr. Gowland and appended to this paper. Although the country may be looked upon as distinctly hilly, there are no great elevations in the southern provinces. Occasional peaks may attain altitudes of 3000 feet; but there is nothing comparable to the heights observed in the Pepi-shan mountains of the north. The highest point reached by Mr. Gowland was attained in crossing, at a point about 20 *li* * south-east of Brambe, the range of mountains which runs the whole length of the peninsula.

Before the treaties of 1883, by which Europeans were admitted to the country, nothing whatever was known of the geological structure of the interior of Korea; the only observations made being on the numerous islands in the adjacent seas and on parts of the coast-line. The earliest geological observations recorded were made by Capt. Basil Hall, R.N., in 1818, and are set forth in an appendix to his "Account of a Voyage of Discovery to the West Coast of Corea and the Great Loo-Choo Island." Beyond the mention, in 1834, by the Rev. Chas. Gutzlaff †, of the occurrence of columnar "bay-salt" on the west coast, nothing more was done with regard to the geology of the country until Dr. Gottsche, taking advantage of the treaty with Germany in 1883, undertook a tour through the country in the latter part of that year and the beginning of 1884. The observations then made were published by Dr. Gottsche in 1886 ‡, together with a paper on the petrographical results by Prof. J. Roth §.

Whilst a careful study of the specimens in Mr. Gowland's collection has led to a confirmation, in general, of the results obtained by the above-mentioned authors, I consider that, from the fact of their being obtained for the most part in localities not visited by Dr. Gottsche, a description of them might prove of some interest as an addition to our knowledge of the geological structure of Korea ||.

* A Korean *li* is about one third of an English mile.

† *Op. cit.* p. 233.

‡ Sitzungsber. k. Akad. Wissensch. Berlin, vol. xxxvi. (1886) p. 857.

§ *Ibid.* p. 875.

|| An interesting account of the general characters of the country and people will be found in a paper by Mr. W. R. Carles, H.M. Vice-Consul in Korea, in the 'Proceedings of the Royal Geographical Society,' vol. viii. (1886) pp. 289 to 312.

## III. Igneous Rocks.

Dr. Gottsche, in classifying the specimens he obtained from Korea, divided the igneous rocks into an older eruptive series (*ältere Eruptivgesteine*) and a younger eruptive series (*jüngere Eruptivgesteine*). In the former group he includes granite, granite-porphyry, felsite-porphyry, diorite, hornblende-porphyrite, gabbro, and diabase; whilst basalts and dolerites are the only Korean igneous rocks which are not, according to Dr. Gottsche, of pre-Tertiary age. As it is impossible, in the central and southern provinces, to do more than prove that the eruptive rocks are of a later date than the crystalline schists, I shall classify the rocks only with reference to their structure and composition.

There is abundant evidence of former igneous action, both plutonic and volcanic, in this country as well as in the neighbouring parts of China, described by Von Richthofen; but there is no evidence of present volcanic activity, nor is there any record of earthquake-action within the memory of man. The only manifestations of the activity of internal forces consist in a few hot springs in different parts of the country. Dr. Gottsche mentions the occurrence of such springs, having a temperature of 76° C., near Tongnai, Kyöng-sang Do; and in the north at Tamni, north of Unsan, in Phyöng-an Do, having a temperature of 45° C.* Mr. Gowland found a hot spring at Brambe near the base, on the north-west side, of the Mungyong pass. The water of this spring had a temperature of 105° F. (45°·5 C.) in the bath; it was perfectly clear and transparent; without action on litmus, quite devoid of taste or smell, and leaving no deposit.

### (1) *Acid Eruptive Rocks.*

#### a. *Plutonic.*

Of the eruptive rocks, granite seems to be by far the most abundant in the southern provinces, forming most of the principal hills and exhibiting its characteristic weathering on the craggy summits.

In the mountains to the north and west of Söul, curiously weathered crags of a coarse-grained granite rise to a height of 2000 feet. A specimen of this rock in Mr. Gowland's collection has a specific gravity of 2·613. Under the microscope the large grains of quartz are seen to contain the usual bands of secondary inclusions. In places the quartz itself is secondary, and is seen to encroach on a decomposing orthoclase, sometimes retaining the kaolinized products, which show the old line of demarcation between the crystals. Vermicular chlorite is occasionally included. Orthoclase occurs in large flesh-coloured crystals, frequently kaolinized in the centres. Decomposition has given rise to the secondary formation of minute nests of a colourless, micaceous mineral, possessing a high double

* *Op. cit.* p. 862.

refraction. Occasional flakes of these are of sufficiently large dimensions to determine the biaxial character of the crystals. Similar brightly polarizing crystals have been frequently observed. Dr. Hatch, for example, refers them to muscovite or kaolin *. Plagioclase is represented in the Söul granite by smaller crystals exhibiting extinction-angles agreeing with those of oligoclase. Albite and muscovite are found associated as secondary products, infilling cracks in the rock. Most of the biotite originally existing in the rock has been converted into chlorite, which exhibits the pleochroism : E = yellowish-green, O = dark green, and which, when treated with sulphuric acid, decomposes with the formation of gelatinous silica. Of accessory minerals, magnetite occurs, and less abundantly apatite.

In the coarse-grained granite of Söul there occur veins of a much finer-grained dark grey biotite-granite. Many of the crystals in this rock seem to exhibit signs of growth after the formation of the original crystal-outline (fig. 1). Much of the quartz, by intergrowth

Fig. 1.

Crystal of orthoclase showing secondary extension of the felspathic material, irregularly intergrowing with the neighbouring crystals. In biotite-granite from the mountains north-west of Söul.

with the other crystals in the rock, produces a distinct pegmatitic structure. Colourless acicular inclusions are common in the quartz. Although the felspars, both orthoclastic and plagioclastic, are distinctly kaolinized, the biotite has undergone little or no apparent alteration; chlorite is present in very small quantities.

Near the boundary between the provinces of Kyong-kwi Do and Chhung-chhöng Do, between Yukei and Eumsong, and for some miles around the latter town, there is an extensive development of

* 'The Spheroid-bearing Granite of Mullaghderg, Co. Donegal,' Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 550.

granitic rocks, breaking through the crystalline schists in that area, and forming the low rounded hills of the district. A specimen taken from Castle Hill, Eumsong, is a medium-grained rock, with a specific gravity of 2·61. Under the microscope, we recognize quartz, in granular crystals, biotite, changing into chlorite, orthoclase, considerably kaolinized, and plagioclase, exhibiting examples of crystals with a progressive zonal development from a more basic plagioclase in the centre to the more acid types at the periphery. From its microscopic characters this rock would come under the definition of the *granitite* of Gustave Rose. A closely related rock, but more decomposed, and having a specific gravity of 2·58, occurs near Fusan, Kyöng-sang Do.

A specimen of pegmatite, found by Mr. W. G. Aston near Söul, is almost devoid of mica, and consists of a decomposed aggregate of flesh-coloured felspar and quartz. The rock might be described as an *aplite*. Aplite has been described by Prof. Roth * from Tsushima, an island off the south-east coast of Korea; and Capt. Basil Hall describes some specimens from two small islands on the south-west coast, lat. 34° 23′ N., long. 126° E., as "a decomposing, fine-grained rock with flesh-coloured orthoclase, white quartz, and porcelain clay" †.

Besides the above-selected localities, granitic rocks are found in various parts of the country breaking through the crystalline schists, and forming, in the southern provinces, the principal factor in the formation of the mountain-peaks and -chains; one of the highest in the south being Mount Kimonsangsan, reaching an altitude of about 3000 feet, situated W.S.W. of Sönsan, in west Kyöng-sang Do. Mr. Gowland has found rocks of similar type cropping out also at the following places along the line of route:—In Kyong-kwi Do, at Yong-in, about 70 *li* south of Söul, at Pekkemmi, north-west of Chuksan, and at Chuksan; in Chhung-chhöng Do, at Chhung-ju, at Brambe, and at various points over the Mungyong pass to the province of Kyöng-sang, where granite occurs at Yuko, 40 *li* S.S.E. of Mungyong, and thence at intervals to Hamchhang, Sangju, Sönsan, and Haiphyong. At Yangsan it is again exposed, and occurs plentifully along the route from that town to the coast at Fusan.

The granite is found in all stages of decomposition in the same district. Near Söul, for example, there is to be found a beautiful example of the decomposed rock in which the felspathic constituents have been almost wholly reduced to a powdery mass of kaolin, leaving the unaltered quartz-crystals, and, here and there, a clear plagioclase, whilst cubes of pyrites, of from 2 to 5 millim. edge, have been developed. The rock gives no effervescence with dilute acids.

*Eurites.*—Acid eruptive rocks are found varying in crystalline characters from the true granitic type to those presenting the

* *Op. cit.* p. 876.
† *Op. cit.* Appendix, p. cxxviii.

characters of rocks which are known as felsites and eurites *. They occur in various parts of the country breaking through the crystalline schists and granites.

Between Chhungju and Brambe, Mr. Gowland obtained specimens of a mass of eurite breaking through granite. The rock has a specific gravity of 2·53. Amongst the porphyritic constituents the most conspicuous are quartz, in large transparent crystals, and Carlsbad-twins of orthoclase. The rock is stained with ferruginous decomposition-products, and contains irregularly-scattered minute cubes of hydrated oxides of iron occurring as pseudomorphs after pyrites. Small flakes of biotite are not uncommon. Prof. Roth has described a somewhat similar rock as a granite-porphyry from a locality between Paikchi and Ikujang, in the western province of Hwang-hai †.

In the Mungyong pass, the larger quartz-crystals of the eurites exist in well-developed bi-pyramidal forms, the faces being generally considerably etched. Orthoclase, plagioclase, and hexagonal plates of biotite occur in association with the quartz. Iron pyrites and magnetite are present in smaller quantities. In a pass a little to the west of Chhungju Mr. Gowland secured specimens of a similar rock, with a specific gravity of 2·56. Eurites occur also S.E. of Undon, and, like the granites, are frequently traversed by veins of quartz.

b. *Volcanic.*

Corresponding in chemical composition with the foregoing there occur in Korea rocks which, from the structures they exhibit, have had an undoubted volcanic origin, and which have, since their eruption, suffered from a devitrification of their originally glassy magmas, with a production of a secondary felsitic structure, similar to the structure exhibited by many ancient British lavas with which we are familiar from the researches of Rutley, Allport, and Bonney.

In the province of Chhung-chhöng, there occurs to the S.E. of Chhungju an example of this nature associated with granitic rocks. The compact, greenish or greyish hand-specimen shows distinct banding; and this is confirmed under the microscope by the fluidal arrangement of the microliths around the porphyritic constituents. With crossed nicols, the field becomes broken up into doubly-refracting patches with no apparent relation to the irregularly distributed masses of nebulous, green, and brown material. Quartz occurs in irregular grains and as bi-pyramidal crystals; and, in greater abundance, orthoclase in flesh-coloured crystals. The relics of partially decomposed felspars show that plagioclase was by no

* The name 'eurite' has been shown by Messrs. Cole and Jennings (Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 433) to have been employed with scientific precision by d'Aubuisson before such names as 'felsite,' 'quartz-porphyry,' &c. were proposed. I have, therefore, thought its use preferable to the terms more commonly employed in this country.

† *Op. cit.* p. 876.

means an unimportant constituent of the original rock. During the changes which the rock has undergone, epidote has been formed, biotite has been changed into chlorite, and a considerable development of secondary quartz occurs, infilling cavities produced by the removal of decomposition-products from the felspars. Magnetite occurs in cubic crystals. The rock has a specific gravity of 2·64. Prof. Roth records the occurrence of a somewhat similar rock from Puphyöng, Kyöng-kwi Do, and another from Deer Island, off the coast near Fusan *.

Specimens of an acid volcanic rock were obtained by Mr. Gowland south-east of Milyang, in the province of Kyöng-sang.

Porphyritic crystals of clear quartz and decomposed felspar are seen embedded in a grey fluxion-structured matrix. Occasional fragments of green material, apparently caught up in the mass, are found, on microscopic examination of the section, to be included masses of altered rocks of the andesitic type. Many of the quartz-crystals exhibit the geometrical outlines of idiomorphic crystals; the majority, however, are so far corroded by the magma as to be devoid of any trace of original form. The greatly kaolinized felspars are seen in some cases to exhibit plagioclastic twinning. An interesting example of the micrographic intergrowth of quartz

Fig. 2.

Micrographic intergrowth of quartz and felspar, some of the latter being plagioclastic, and the whole considerably decomposed. The quartz has extended its borders with an attempt at the formation of its normal, crystalline outline; and has, by the development of alternate forms, produced a rude 'babel' quartz. In felsitic lava from Milyang, Kyöng-sang Do.

and felspar is represented in fig. 2, in which it will be seen that the quartz has, by secondary growth, increased at the borders with an

* *Op. cit.* p 876.

attempt at the assumption of its normal crystallographic outline, and producing, by alternate development of forms, an imperfect example of "babel" quartz.

Hydrated ferruginous products, titanoferrite, green chloritic material, and secondary quartz, infilling cracks and cavities, have accompanied the distinct devitrification of the magma. The contortions and twistings (during the original flow of the material) of the patches of unlike chemical composition have given rise to a structure similar to that to which Mr. Rutley has given the name "damascened"*.

### (2) *Intermediate Eruptive Rocks.*

The rocks to which Prof. Judd in 1876 gave the name "intermediate" are represented in Mr. Gowland's collection of Korean specimens only by members of the series in which plagioclase is the predominating felspathic mineral. These comprise examples of plutonic origin as well as those formed as lavas.

#### a. *Plutonic.*

*Diorite.*—An exposure of a fine-grained variety of this rock occurs in a gorge near Yukei, in the province of Chhung-chhöng. Scattered through a fine-grained, almost aphanitic groundmass are patches of coarser-grained aggregates of hornblende and felspar, forming the "glomero-porphyritic" structure of Prof. Judd. Under the microscope, hornblende, in green and brown crystals, small flakes of biotite, and plagioclase-felspar are seen to be the principal constituents. Occasional granules of quartz, with numerous acicular inclusions of apatite, lumps of magnetite, and rarely crystals of zircon, occur as accessories.

The hornblende in this rock, besides occurring in the form of the numerous small green crystals with an extinction-angle ($c \wedge \mathfrak{c}$) of 15°, is found more rarely in large crystals of a deep brown colour, with a narrow zone of the green variety around, and in crystallographic continuity with the brown mass in the centre. The cleavage is well marked in the brown crystals, which exhibit a very strong pleochroism from $\alpha$ = straw-yellow to $\gamma$ = deep brown. The strong absorption ($\gamma > \beta > \alpha$) increased the difficulty of making an accurate determination of the position of extinction; but 5° was obtained as an average of numerous measurements made from the vertical axis. The properties of the brown variety are thus identical with basaltic hornblende, whilst the green zone exhibits the optical characters of common hornblende.

The major part of the plagioclase-crystals are zoned by a gradual passage into succeeding layers of different chemical composition from the centres of the crystals to their borders. Distinct, narrow, and irregular fringes with a different extinction-angle sometimes surround the crystals, and were apparently formed after the con-

* 'The Study of Rocks,' 1879, p. 181.

solidation of the rock, in the same manner as was shown by Prof. Judd to be the case with the porphyritic plagioclase in the labradorite-andesite of Dun da Ghaoithe, in the Isle of Mull *.

Near Sokul, a small town to the north-east of Söul, occurs a medium-grained, friable rock, with a specific gravity of 2·82, in which quartz, felspar, black mica, hornblende, and sphene are recognizable. In addition to these, the microscope reveals the presence of such accessories as apatite, in bacillar crystals, zircon, and magnetite. The brown "uniaxial" mica and hornblende are found intimately intergrown; the latter sometimes exhibiting its idiomorphic outlines. Cross-sections of such hornblende crystals sometimes show, in addition to the more usual prismatic and clinopinacoidal faces, the traces of the orthopinacoidal plane. The pleochroism is $\alpha$ = straw-colour, $\beta$ = grass-green, $\gamma$ = bluish green, and the extinction-angle varies from 13° to 15°. Twinning on the plane 100 ($\infty$ P $\infty$) commonly occurs. The biotite seems to be more generally included in the hornblende, the latter being sometimes quite subordinate in quantity, and occasionally existing merely as irregular and discontinuous fringes to the mass, but which may be recognized, from the same physical orientation over large areas, as fragments of one crystal.

Of the felspars, plagioclase predominates. The crystals are frequently composed of zones having different extinction-angles, and in the centres are frequently kaolinized over a definitely marked area, the surrounding zones being apparently untouched by weathering agents. These centres are so well marked, and so deeply decomposed, that one might well suspect their allothigenous origin, whilst the remainder of the crystal might have been produced during the general and final consolidation of the rock.

Quartz in fair quantity exists as crystals, which are allotriomorphic to the other constituents of the rock.

The presence of sphene is confirmed by the characteristic reactions for titanium obtained during a chemical examination of the rock.

Evidence of the pressure to which this rock has been subjected is afforded in the bent twin-planes of the plagioclastic felspars, and the "undulose" extinctions of the quartz crystals.

Mr. Gowland obtained, in a stream S.E. of Yuko, pebbles of a rock somewhat similar in mineral composition, but coarser in crystalline character. Owing to the depth of the soil, exposures were rare in this district; and consequently their absence prevented the determination of the geological characters of the area. Mr. Gowland was compelled at this part of the journey to contend with somewhat exceptional difficulties from the hostility of the natives, who several times attempted to stone him and his party, until, at Taiku, he was rescued by the guards sent by the Governor, and thus accompanied throughout the route to the coast.

* Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 178.

b. *Volcanic.*

An interesting series of rocks of the andesitic type occurs in Korea. The specimens I have examined invariably exhibit signs of secondary changes, resulting, in some cases, in a devitrification, more or less complete, of an originally glassy matrix, and passing gradually into the structures characteristic of the rocks to which Von Richthofen gave the name of propylites. This change is sometimes accompanied by others due more precisely to subaërial agencies, whereby we find the original alkaline and ferro-magnesian silicates replaced by chlorite, epidote, and calcite; whilst magnetite has been oxidized and hydrated to the usual ferruginous products.

Between Indong and Tawön, Mr. Gowland found boulders of a black, glassy-looking, porphyritic andesite in the river-bed. The specimens were associated with stratified sandstones, grits, conglomerates, and dark slaty rocks of doubtful stratigraphical position *. The andesite, under the microscope, exhibits the most beautiful fluidal structure. Patches of brown, black, and green microliths have been formed in the moving mass. The brown and black microliths, which are seen under the higher powers to be merely minute specks and streaks of ferruginous material, have aggregated into wisp-like radial groups with irregularly curved outlines. These minute bodies closely resemble the minute black rods and granules of magnetite observed by Prof. Judd in a magma-basalt from Gribun, Isle of Mull †.

Although the matrix appears so beautifully glassy, it is seen under polarized light to be completely devitrified in granular areas, which are apparently formed irrespective of the spherulitic aggregates of microliths.

The most prominent porphyritic constituent is plagioclase, in large crystals very slightly affected by kaolinization. Twinnings, both on the pericline- and the albite-type, are exhibited, and the crystals are occasionally zoned from change of chemical composition during growth. The grouping together of the felspars occurs in such a manner as to suggest the "glomero-porphyritic" structure of Prof. Judd, thus pointing to their probable allothigenous origin. Occasionally the felspars have been decomposed in the centre, and the cavities infilled with quartz (or, perhaps, albite). On stirring the crushed and sifted rock in a heavy solution of borotungstate of cadmium, the majority of the white felspathic grains were just held in suspension when the liquid possessed a density of 2·66, thus showing them to be of a composition bordering on andesine and labradorite. This is confirmed by the results obtained in an examination by Szabó's method of flame-reactions. It was found that nine grains agreed closely with the characters given by Prof. Szabó for andesine, whilst six grains showed the characters of labradorite. A silica determination of the very small quantity

* Dr. Gottsche marks this district in his map as being probably of Carboniferous age.

† 'On the Gabbros, Dolerites, and Basalts of Tertiary Age in Scotland and Ireland,' Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 69, and pl. vi. fig. 7.

available gave 56·45 per cent. of silicic acid, the mineral being thus slightly more acid than the compound $Ab_1 An_1$ *.

Secondary quartz with chlorite and acicular apatite infill cavities which present the characteristic shapes of the pyroxenes originally in the rock. Together with the quartz, occasional lumps of magnetite and, more rarely, granules of yellowish-green epidote occur in these cavities. The rock has a specific gravity of 2·65.

A porphyritic andesite occurs about 15 *li* south-east of Milyang, in Kyöng-sang Do. The specimens have an average specific gravity of 2·62. Under the microscope, the fluidal structure is distinctly shown by the bands of dusty microliths in the brown matrix. The black and brown microliths are so closely felted (*Mikrolithenfilz*), that it is impossible to determine the interstitial glass. Throughout the sections, and following the direction of flow, there are granophyric bands, which, in places, distinctly exhibit the structure to which Becke, in 1881, gave the name of "centric." From the way in which these bands are drawn out in the direction of flow, they suggest the existence, in the molten material, of bands of different chemical composition; but there is not, in the present case, any evidence to prove that the structure has been formed in the manner suggested by Prof. Lagorio †, or whether it is the result simply of secondary changes. It is worthy of note that the felspathic material thus intergrown with the quartz is invariably decomposed and kaolinized; and the same structure has, in other cases, been proved to be of secondary origin by Prof. R. D. Irving ‡, Prof. J. W. Judd §, and Miss Raisin ‖.

The plagioclastic felspars are represented in this rock by clear, glassy crystals, which, when examined by Prof. Szabó's method of flame-reactions, agreed in character with oligoclase; and, on separation from the crushed matrix by means of a solution of borotungstate of cadmium, were found to possess a specific gravity of 2·65. In some cases it is easy to prove that the felspars were formed as such before the rock in which they are now found—that, indeed, some of them previously existed as porphyritic constituents of a plutonic rock. In fig. 3, I have represented a case in which a plagioclastic crystal is seen to possess a centre probably much older than the surrounding zones. The central core has been schillerized in four distinct planes, the inclusions being arranged in lines crossing one another at the angles shown in the diagram (fig. 4). There is evidence of corrosion of this central core, and, afterwards,

* Owing to an accident, part of the bulk analysis of the rock was lost. The silica, however, was found to amount to 68·42 per cent.; in this respect the result of the analysis closely resembles that obtained from the dacite-glass of Krakatoa, described by Prof. Judd ('Report of the Krakatoa Committee of the Royal Society,' 1888, pp. 31, 32, and 34).

† 'Ueber die Natur der Glasbasis, sowie der Krystallisationsvorgänge in eruptiven Magmen,' Tschermak's Min. u. Petrogr. Mittheil. vol. viii. p. 421.

‡ U. S. Geol. Survey, Monograph V.—The Copper-bearing Rocks of Lake Superior (1883), p. 113, pl. xiv. figs. 1, 2, 3, & 4; and pl. xv. fig. 4.

§ Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 73, pl. vii. fig. 8.

‖ *Ibid.* vol. xlv. (1889) pp. 252 and 253.

of accretion in zones of a decidedly more acid character. Some of the twin-planes of the central, old core are common to the surrounding zones, and run the whole length of the compound crystal;

Fig. 3.

Crystal of porphyritic plagioclase with a core of older, felspathic material which has been schillerized in four directions and corroded before the formation of the clear zones of a less basic character around. In addition to the series of twin-planes running the whole length of the crystal, another set, perhaps older, are limited to the central schillerized core. In andesite from Milyang, Kyŏng-sang Do.

Fig. 4.

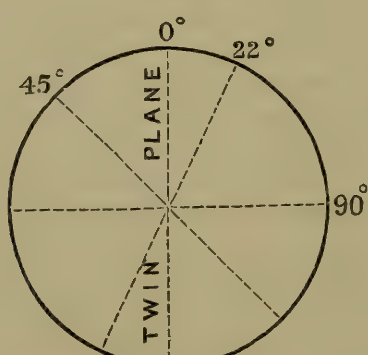


Diagram showing the directions of the planes of schillerization in the above (fig. 3).

but there are a large number which extend out only to the borders of the schillerized patch. These latter, perhaps, existed before the formation of the new felspathic material around them.

Magnetite, in cubic crystals, is scattered throughout the rock. The original ferro-magnesian silicate seems, from the shapes of the masses of secondary products, to have been a pyroxene. It is now replaced by viridite, magnetite, granular epidote, and quartz.

Fragments of other andesites are caught up in the rock. They exhibit a greater development of lath-shaped crystals, and, from the amount of ferruginous material present in them, are apparently derived from rocks more basic in character.

Specimens of a vesicular andesite were found in the same district, a little nearer Milyang. The plagioclase-felspars, frequently almost wholly converted into epidote, are arranged in a direction parallel to the flow of the rock. The vesicles are frequently lined with opaline silica, and sometimes filled with brightly-polarizing radial aggregates of zeolites. The opaline silica is seen under high powers to be composed of minute, globiform bodies, similar to the structures figured and described by Vogelsang from the so-called quartz-trachyte of Hliniker Thal, Schemnitz *. The opal is stained green, and frequently drawn out into streaks. In opal similarly occurring in a hornblende-dacite from Santorin, MM. Fouqué and Michel-Lévy suspected the green staining to be due to the presence of silicates of iron and magnesia †.

Small plates giving dull polarization-colours suggest the presence of tridymite; but although many of these are hexagonal in outline, I have found no definite cases attributable to the characteristic fan-like twins described by Vom Rath. Silica has crystallized in this rock also as secondary quartz. The relics of the porphyritic felspars give extinction-angles which indicate a composition more basic than that of the small, lath-shaped crystals exhibiting binary twinning. Assuming the latter crystals to be developed along the edge $oP : \infty P \infty$ (001 : 010), as pointed out by Michel-Lévy ‡, then the microliths in the present case have a chemical composition closely agreeing with that of oligoclase. They are more acid, and probably belong to a later period of consolidation than the larger crystals, which are thus porphyritic in the sense in which that term is employed by Rosenbusch §. The porphyritic felspars are greatly kaolinized, and have frequently been partially converted into yellowish granular epidote, which occurs in some cases as isolated granules, and at other times is spread out in patches, extending to the borders of the felspar-crystal, but never exceeding such limits. These facts agree with Mr. Rutley's suggestion as to the formation of epidote from kaolin, by the secondary action of carbonates of lime and iron in solution ||. In a rock like this, vesicular in structure and abounding in zeolites and hydrated ferruginous products, the conditions could not have been

* 'Die Krystalliten,' 1875, p. 139, pl. xv. fig. 1.

† 'Minéralogie micrographique,' 1879, p. 179, pl. xviii.

‡ Annales des Mines, sér. 7, vol. xii. p. 451.

§ 'Ueber das Wesen der körnigen und porphyrischen Structur bei Massengesteinen,' Neues Jahrbuch f. Min. &c. (1882) p. 13.

|| 'On the possible origin of some Epidosites,' Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 740.

unfavourable to such a change being brought about in a kaolinized felspar.

The ferro-magnesian silicates which originally existed in the rock have been destroyed ; but the casts of secondary products bear the form of hornblende crystals. Around each crystal there is a zone of opacite (magnetite ?) granules, so commonly occurring in hornblende-andesites—for example, in that of Altsohl, Hungary. Sometimes, however, the whole crystal has been destroyed. If these borders be due to decomposition subsequent to consolidation, one might reasonably expect that the changes would extend to the centres of the crystals in a case where alteration has been so thorough. It seems more likely that the dark zones have been produced by the caustic action of the magma before consolidation, and after the relief of pressure in the rock, as in the manner suggested by Zirkel *, and confirmed by the experiments of Becker †.

### (3) *Basic Igneous Rocks.*

The basic rocks are especially well represented in the southern provinces, where they break through the crystalline schists, palæozoic rocks, and granites. The same succession has been observed by Dr. Gottsche in several parts of the country, and Capt. Basil Hall mentions a "whin" dyke cutting through the micaceous schists on Hutton's Island (lat. 36° 10′ N., and long. 126° 13′ E. ‡).

The basic rocks which have been collected by Mr. Gowland are all fine-grained in texture, and have, in nearly all instances, undergone considerable alteration ; they may be classed as altered varieties of dolerites and basalts. There is a gradual passage represented from the intermediate to the basic group; and in some cases it becomes a matter of considerable difficulty to distinguish augite-bearing andesites from the basalts.

Although the examples of basic rocks from the southern provinces are nearly all altered to a considerable extent, there occur, to the north-east of Söul, plateaux of basaltic lavas of comparatively recent date. These are mentioned by Dr. Gottsche and by Mr. W. R. Carles §. Besides these inland occurrences, Charles Gutzlaff, in 1834, recorded the occurrence of columnar "bay-salt" on the west coast near Changsan ‖.

* Ueber d. Kryst. Gesteine längs d. 40-Breitgrade in N. A,' Bericht k. Sächs. Gesellsch. Wissensch. (1877) p. 181.

† "Ueber die dunklen Umrandungen der Hornblende und Biotite in den massigen Gesteinen."

Prof. Judd, in his paper on the 'basic' rocks of Scotland and Ireland (Q. J. G. S. vol. xlii. (1886) p. 79), refers to the crystallization, in the effusive basic rocks, of large quantities of magnetite, which must, in the deep-seated types, have crystallized out in the ferriferous enstatites. In these andesites, therefore, there might be, on eruption and relief of pressure, a corrosion of the ferriferous silicates, previously formed under greater pressure.

‡ *Op. cit.* Appendix, p. cxxv.

§ Proc. Roy. Geogr. Soc. vol. viii. (1886) p. 305 *et seq.*

‖ *Op. cit.* p. 233.

Amongst the specimens collected by Mr. Gowland, one of the freshest types of basaltic rock obtained was from a river-gorge near Chhöngdo, in the province of Kyöng-sang. In the hand-specimen the rock is a dark-green, compact variety, with an abundance of long felspar-crystals arranged in approximately parallel directions. The specific gravity of the rock is 2·81.

The porphyritic felspars, judging from the angles of extinction measured, have a composition approximating to that of bytownite. They are well twinned, principally on the albite type, and contain frequent inclusions of glass, especially in marginal zones. These crystals are porphyritic also in the sense in which this term is employed by Rosenbusch. The early consolidation of these large crystals of felspar is further indicated by the occasional occurrence of specimens which have been split asunder along the *Gleitflächen* and cleavage-planes, with intrusions of the matrix, which has either crystallized out, like the general matrix of the rock, or consists solely of augite, which has been partly changed into green fibrous hornblende.

The original ferro-magnesian silicate has been converted into the various green decomposition-products. In some cases, this is distinctly serpentine, either alone or mixed with chlorite. Patches of green fibrous hornblende, with its characteristic pleochroism, occur with these green products.

The constituents of the matrix have consolidated in the order which they follow in the description: Magnetite occurs in well-marked, cubic forms, seldom accompanied by titanoferrite. Small, lath-shaped crystals of plagioclase are abundant, both in binary and in repeated twins, which, from their angle of extinction, are closely allied to labradorite or andesine. Augite fills in the intervening spaces, with the formation of the ophitic structure of M. Michel-Lévy on a small scale—the micro-ophitic structure described and figured by Prof. Judd in certain basaltic lavas of Mull *. The augite in the Chhöngdo rock has partly changed into uralitic hornblende. The occurrence of ophitic structure indicates, according to Prof. Judd, consolidation of the rock under conditions of comparative quiescence; hence in this rock the porphyritic felspars must have acquired their approximately parallel directions before complete consolidation, or before the rock assumed the quiet conditions preparatory to solidification. As might be expected from this, the microlithic felspars of the groundmass exhibit, with regard to direction, no such regularity of arrangement.

A compact dark-green porphyritic basalt occurs S.E. of Milyang, in Kyöng-sang Do. The specific gravity of the rock is 2·80. Under the microscope, plagioclase, augite, and magnetite are porphyritically developed in a finely granulitic matrix. "Progressive" zones, due to changes in the chemical composition of the crystallizing magma, not unfrequently characterize the plagioclastic crystals. Between the extinction-angles of the outer zones of the

* Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 68, and pl. v. figs. 3, 5, & 7.

porphyritic crystals and those of the smallest felspathic microliths there is a curious correspondence, the larger crystals of the matrix being found to correspond to the inner zones, which exhibit gradations to anorthite. Zonal inclusions of the vitreous magma are common; and decomposition, with the formation of brightly polarizing flakes of a hydrous mica, muscovite, zeolite, or kaolin, has frequently destroyed the centres, or extended along fracture-cracks in these crystals.

Augite occurs in very large and almost colourless crystals, which have suffered from incipient uralitization and separation of dusty magnetite, together with the formation of chlorite, occasionally vermicular, and secondary quartz in the cavities.

In the matrix of the rock there are small fibrous hornblende-crystals interspersed with cubic granules of magnetite. Epidote occasionally accompanies other secondary minerals in the cavities. It is impossible to form any reliable estimate as to the amount of glass in the rock after its primary consolidation.

A further stage in the decomposition of the Korean basic rocks is exemplified in a specimen from the hills behind the Fusan settlement, in the south-east of the peninsula. The porphyritic plagioclase-felspars, which are exceedingly numerous, have been almost completely kaolinized, and a considerable amount of epidote formed in granular crystals and radiating branches, together with chlorite and the usual green products of an altered basic magma. There are irregular straw-coloured patches of material, in many respects serpentinous in appearance. Mr. Rutley mentions the occurrence of a somewhat similar substance in the augite-andesites of St. Minver, Cornwall *.

The original ferro-magnesian silicates have been utterly destroyed. Magnetite is plentifully scattered in small crystals. The specific gravity of the specimens in Mr. Gowland's collection averages 2·78.

A compact dark green rock from the Mungyong pass contains a large amount of calcite, which effervesces with cold acids. The specific gravity of the rock is 2·815. The felspars are seen, under the microscope, to be converted completely into zeolitic products, which give brilliant aggregate polarization-colours. Small granular crystals of augite, showing the usual twin-phenomena and frequent zoning, occur in great abundance scattered through the section. In one section, two large quartzes, with the usual bands of inclusions, have evidently been entrapped in the rock and partially fused. Around each of the crystals, which are situated very close to one another, there is an inner zone of brown, felsitic material not unlike the matrix in many of the acid felsites, and it seems in this case to have been produced by the fusion of the quartz with the more basic matrix in which it occurred as a foreign inclusion. Outside the felsitic zone there occurs a zone of granular crystals,

* 'On some Eruptive Rocks from the neighbourhood of St. Minver, Cornwall,' Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 393. Mr. Rutley (footnote, *ibid.* p. 393) quotes Prof. Bonney's opinion as to the palagonitic nature of some of the yellow patches.

each with a high refractive index, strong double refraction, and wide extinction-angle. These granules, so far as it is possible to determine, present all the characters of the granular augites of the matrix. Quartz crystals zoned around in this manner in the magma were mentioned by Prof. Zirkel as occurring in some augite-andesites of Arran *. More recently Dr. Hatch has observed similar sporadic quartz-crystals in some specimens collected by the Rev. Mr. Baron in Madagascar †.

Secondary quartz and chlorite occur in this rock. Magnetite exists in abundance. The high powers of the microscope reveal the presence in the matrix of a series of yellow-brown pleochroic crystals of (probably) hornblende.

A rock having a specific gravity of 2·73, from a river-gorge near Chhungdo, presents, in the hand-specimen, characters similar to the foregoing example. It is dark-green and compact, with an abundance of stout prismatic crystals of plagioclase, which, with augite, form the principal porphyritic constituents. As shown by their extinction-angles, the felspars vary in chemical composition from labradorite to bytownite. The crystals are frequently split along the gliding-planes with intrusions of the magma. The augites are partly converted into hornblende, with bye-products of epidote and chlorite. Iron oxides occur as granules of magnetite, and as smaller flakes of red hydrated products, scattered through a grey matrix of closely felted plagioclase-microliths, exhibiting a fluidal arrangement. The structure presented in the matrix of this rock is similar to that to which Rosenbusch gave the name "pilotaxitic" ‡, and might have been at one time hyalopilitic. This rock presents many of the appearances of the true andesites or propylites ; in fact, the majority of the specimens obtained from the south-east of Korea exhibit characters bordering on the augite-andesites, propylites, and basalts.

In an andesitic rock from Pumasa, we have examples of the complete uralitization of augite. In addition to these, some of the crystals, whilst retaining the cleavage, form, and twin-structures characteristic of augite, exhibit the peculiar pleochroism of hornblende. A separation in lines of dusty magnetite frequently characterizes the uralitic crystals. The large plagioclase-felspars of rather a basic type are rendered cloudy in appearance by the inclusion of a very fine, black dust, the particles of which are scarcely capable of distinct individualization even under high powers of the microscope ; and, although frequently occurring arranged along irregular, curved lines, they sometimes occur in rectilinear bands parallel to the twin-planes. From the way in which they follow in intensity the zoning of the crystals, they present the appearance of being original. Dr. Hatch mentions the occurrence of similar dusty inclusions in the felspars of a Malagasy olivine-

* 'Geologische Skizzen von der Westküste Schottlands,' Zeitschr. Deutsch. geol. Gesellsch. vol. xxiii. (1871) p. 28.

† Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 347.

‡ 'Mikr. Phys. mass. Gest.' 2nd ed. p. 466.

norite *, whilst the same thing has been observed by other authors, recently by G. H. Williams in a hypersthene-gabbro of Baltimore †. Large crystals of apatite occur, both in the matrix and included in other minerals. The groundmass of the rock consists of a plexus of colourless felspar-microliths, brown and green hornblende, granules of magnetite, and interstitial glass, forming the "hyalopilitic" structure of Rosenbusch. Secondary quartz, as granular crystals, fills in the cavities.

Some of the extremes of alteration of this class of rocks occur near Fusan and Chhungdo. Nests of epidote, quartz, actinolitic hornblende, and magnetite weather out on the exposed surfaces as knobby projections. In the specimens obtained from Chhungdo, chlorite and epidote almost solely constitute the decomposition-products.

In Kyöng-sang Do especially, rocks of the foregoing types are extremely common, and many of them from different localities have been described by Prof. Roth, in the memoir so frequently referred to, as diabase and diabase-porphyry, several also containing calcite. Capt. Basil Hall mentions the occurrence on an island on the west coast, in lat. 37° 45′ N., of a "dark-olive, steatitic rock, containing fragments of granular marble" ‡.

The alteration of the felspar and other constituents into epidote sometimes presents a different phase from that described above, in a general formation of innumerable, disseminated, colourless plates or granules of the mineral, either scattered loosely or gathered into ill-defined aggregates. Patches of granular magnetite occur, perhaps as relics of former ferro-magnesian silicates; whilst secondary quartz fills up the cracks and cavities. Some of the plagioclases still retain faint traces of twinning-phenomena between the granules of the epidote. Examples exhibiting these structures occur in the hills on the east of Pumasa, about 21 *li* north of Tongnai, in the province of Kyöng-sang. A specimen collected by Mr. Gowland is dark-green in hand-specimen, and has a specific gravity of 3·03.

## IV. Metamorphic Rocks.

The most extensively developed amongst the Korean rocks are the crystalline schists of probably Archæan age. From Von Richthofen's descriptions, we learn that this same group is most conspicuous also in the northern provinces of China, exhibiting—in the province of Shantung—a general S.W.–N.E. strike §.

Dr. Gottsche recognizes in Korea two divisions of these rocks:—(1) A lower group of gneisses and mica-schists (*Gneiss-Glimmerschiefergruppe*), with a general strike of S.W. and N.E., as shown in the rocks near Kwisan, Chhung-chöng Do, and between

* Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 343.

† 'The Gabbros and associated Hornblende-rocks of Baltimore,' Bull. U.S. Geol. Surv. no. 28, p. 21.

‡ *Op. cit.* Appendix, p. cxxiv.

§ 'China,' vol. ii. pp. 221 and 706.

Kwachhön and Söul. (2) The upper group of phyllites (*Phyllitgruppe*), with a general N.W. and S.E. strike, and north-easterly dip, as shown in the chiastolite-slate of Mungyong and Hamchhang.

The former group includes mica-schists and gneisses, hornblende-, chlorite-, and talc-schists, crystalline limestones, dolomite, eklogite, and micaceous iron-ore. The phyllite-group includes various phyllite-, chiastolite-, quartz-, and graphite-schists, as well as micaceous iron-ore.

In the specimens of gneiss which I have examined, biotite is by far the most abundant ferro-magnesian silicate; but a gneiss with two micas was obtained by Mr. Gowland between Yukei and Eumsong, in Kyöng-kwi Do. Dr. Gottsche mentions the occurrence of muscovite as well as biotite in specimens obtained from Hatanggyöm, south of Keumsan, in N. Chöl-la Do *.

The muscovite-biotite gneiss in Mr. Gowland's collection exhibits under the microscope the ordinary mineral constituents of a typical granite, in which muscovite is in excess of biotite, and both of which are curved and bent by the crushing to which the rock has evidently been subjected. The biotite is changing in places into a green, pleochroic form, which shows a deep grass-green colour, with rays vibrating parallel to the fibres, and pale straw-yellow, with rays vibrating perpendicular to the basal cleavage. Bundles of the colourless "biaxial" mica are sometimes interlaminated with the brown, pleochroic variety. This interlamination evidently occurred before the crumpling of the mica-bundles during the dynamic metamorphism which has brought the rock to its present condition. Nests of colourless mica are common in the kaolinized felspars, and in cracks, together with other secondary development of mineral matter.

The felspars, which are of both plagioclastic and orthoclastic varieties, have been considerably kaolinized. Occasionally a peculiar intergrowth of two varieties gives rise to the structure to which Becke, in 1882, gave the name "micro-perthitic" †. The numerous quartz-crystals present invariably exhibit "undulose" extinctions. Besides the ordinary bands of inclusions running across the crystals, there is a frequent development, along planes, of a series of communicating, irregularly shaped lacunæ and canals. The production of a graphic structure on a small scale results from the frequent intergrowths of quartz and felspar. Apatite is present as acicular crystals. The gneissose structure is quite apparent; but the rock presents all the appearances of a simply crushed granite.

Evidence of more complete dynamic metamorphism is afforded in various parts of the peninsula. A common type of gneiss may be represented by specimens obtained near Söul, and between that city and Kwachhön towards the south-east. In these rocks we have examples of a true *Augen-gneiss*. Under the microscope, quartz is

* *Op. cit.* p. 862.

† 'Die Gneissformation des niederösterreichischen Waldviertels,' Tsch. Min. und Petrogr. Mittheil. vol. iv. (1882) p. 107.

seen in interlocked granules, and, on a smaller scale, smashed up with felspar into a polarizing mosaic. Bands of these minerals alternate with bands of biotite and a finely granulated, micro-crystalline material, in which it is impossible to individualize the constituents, the whole forming the "Mörtelstructur" of Törnebohm *. It may be observed that in the quartzes the bands of liquid and gaseous inclusions run parallel to one another, and nearly at right angles to the direction of foliation. From these rocks I have separated numerous black scales, which, on chemical and other examination, prove to be graphite. Dr. Gottsche also records the occurrence of graphite in schists from various localities †; whilst Mr. Carles mentions a "bed of graphite" occurring north of Yöngheung ‡; and Capt. Hall noticed that some specimens of schist, with a N.W. and S.E. strike, on a small island near Hutton I., in lat. 36° 10′ N., and long. 126° 13′ E., "appear to contain plumbago" §.

Garnet occurs in eyes of the mineral and in isolated grains, which I have been able to separate from the crushed rock by means of a solution of borotungstate of cadmium, and test separately. Fluor occurs in sufficient quantity to be determined in some cases with the blowpipe.

In a specimen obtained about 10 *li* south-east of Yang-ji, blue crystals presenting the characters of dichroite were abundant. On testing the crushed rock in a solution of borotungstate of cadmium, these crystals were found to sink in a liquid having a gravity of 2·55, and floated easily in a liquid having the gravity of quartz (2·65). The blue grains were just buoyed up at a density of 2·59, and on separation were found to possess all the optical characters of dichroite. Having succeeded in making a chemical analysis of the grains thus separated, I obtained the following result:—

| | |
|---|---|
| Silica | 49·12 |
| Alumina | 32·25 |
| Ferric Oxide | 5·65 |
| Manganese Oxide | tr. |
| Lime | tr. |
| Magnesia | 11·96 |
| Loss on ignition | ·32 |
| | 99·30 |

Comparing these results with analyses of dichroite, there remains no doubt as to the identity of the mineral from the Korean gneiss:—

* Geologiska Förening. Förhandlingar, 1881, vol. v. p. 233.
† *Op. cit.* p. 863.
‡ Proc. Roy. Geogr. Soc. vol. viii. (1886) p. 305.
§ *Op. cit.* Appendix, p. cxxiv.

| | I. | II. | III. | IV. |
|---|---|---|---|---|
| Silica | 49·62 | 49·17 | 48·15 | 50·44 |
| Alumina | 28·72 | 33·10 | 32·50 | 32·95 |
| Ferric Oxide | 12·86 | 4·82 | 8·80 | 1·07 |
| Manganese Oxide | 1·51 | 0·04 | 0·28 | .... |
| Lime | 0·23 | .... | .... | 1·12 |
| Magnesia | 8·64 | 11·45 | 10·14 | 12·76 |
| Water (loss) | .... | 1·20 | 0·50 | 1·02 |
| | 101·58 | 99·78 | 100·37 | 99·36 |

I. From Haddam, Connecticut (specific gravity 2·65). Thomson, Dana's "Syst. Min." 1st ed. p. 278.

II. From Simiutak, Greenland (specific gravity 2·59). Stromeyer, "Untersuch. über die Misch. der Min." &c., Göttingen, 1821, pp. 329 and 431.

III. From Unity, New Hampshire. C. T. Jackson, "Geol. Rep. of N. Hampshire," p. 184.

IV. From Krageröe, Norway. Scheerer, Pogg. Ann. vol. lxviii. p. 319. (Mean of two analyses of pale-blue variety.)

Dichroite was found by Dr. Gottsche in a garnet-gneiss from Songchang, 40 *li* east of Wiwön, Phyöng-an Do. Other accessories, like magnetite, pyrite, talc, chlorite, and, perhaps, tourmaline and topaz, I have noticed in various specimens. Different forms of gneisses are obtained depending on the variability in relative proportions of these constituents. These rocks are found extending sometimes for many miles building up the low rounded hills which characterize Korean scenery in the central and southern provinces, and decomposing into a soil on which rice is extensively cultivated in the valleys and on the plains.

About 18 *li* south-east of Chhungju, in the province of Chhungchhöng, Mr. Gowland collected specimens of a true hornblende-schist, consisting almost wholly of green fibrous crystals of hornblende with secondary quartz formed around the actinolitic crystals, and with occasional patches of graphite and minute magnetite. In the section are to be seen the results of yielding to stresses across the lines of schistosity in the faulting of the hornblende crystals, accompanied by a frequent bending of the fibres near the fault-line. The cracks have been infilled with a detritus of smashed hornblende-crystals, and sealed with secondary quartz and minute plagioclase-felspars. Hornblende-schists were found by Dr. Gottsche in Chöl-la Do and in Phyöng-an Do.

A minutely puckered quartz-mica-schist was obtained by Mr. Gowland between Chhungju and Brambe. The quartz occurs in small granules with white mica and, less abundantly, pleochroic brown mica, the latter often changing to a green. Tourmaline and magnetite are also present. Occasional bands or lenticles of calcite occur, with the granular crystals exhibiting distinct twin-structures. Veins of carbonate of lime occur in this and the neighbouring rocks.

Shales are frequently found exhibiting traces of incipient alteration, with formation of micaceous minerals.

Quartzites were obtained by Mr. Gowland and by Dr. Gottsche in various parts of the peninsula. Dr. H. B. Guppy, during a brief visit of H.M.S. 'Hornet' to the Korean archipelago in 1878, found quartzites and quartz-rock on the island of Mackau. Underneath the quartzite occurred a "highly micaceous rock" and a gneiss traversed by veins of quartz, which also occasionally separated contiguous beds. The dip was 15° E.N.E., thus following the general direction of the upper group of crystalline schists *.

## V. Sedimentary Rocks.

From the researches of Von Richthofen in Northern China, Dr. Gottsche has been able, to some extent, to classify the fossiliferous strata which he met in Korea. In Phyöng-an Do and Hwang-hai Do, in the north, occur patches of Cambrian strata; whilst in the south rocks probably of Carboniferous age are found in Chöl-la Do and Kyöng-sang Do. Dr. Gottsche has also mapped patches of rocks in the three northern provinces † which he regards as Tertiary.

On account of the absence of fossils, Mr. Gowland found it impossible to form any reliable hypothesis as to the age of the stratified rocks which outcropped along the line of route. Some of the sedimentary rocks, however, prove to be of no small petrological interest.

Near Yukei, in the north-east of Chhung-chhöng Do, Mr. Gowland observed in a gorge a good exposure of stratified beds of coarse grit and conglomerate, dipping N.N.W. at an angle of about 24°. A section taken from one of the specimens collected is seen under the microscope to be made up of a variety of rocks, mostly of igneous origin, amongst which various andesites and fragments of granitoid rocks are the most common. Large crystals of quartz with bands of liquid and other inclusions, and flesh-coloured orthoclase, with spindle-shaped, brightly polarizing inclusions, occur either as separate grains or as micrographic intergrowths. The majority of the andesitic fragments exhibit crystals of enstatite in all stages of decomposition. Some of these have a fine-grained grey matrix; others a plexus of lath-shaped crystals, with oxides of iron, either remaining as magnetite or converted into hæmatite and limonite. Chlorite, quartz, and muscovite occur in cracks and cavities as secondary formations.

Between Haiphyong and Indong, in Kyöng-sang Do, there is an extensive development of coarse stratified sandstones, and, in some

* 'Notes on the Geology of the Corean Archipelago,' Nature, vol. xxiii. (1881) p. 417.

† *Op. cit.* pp. 865–870 & pl. viii.

places, conglomerate with well-rounded pebbles. At Indong these beds have a dip varying from 15° to 20° S.E.; and they occur not far from localities in which Dr. Gottsche collected specimens of probable Carboniferous age *. Sections of one of these grits show it to be composed of sub-angular fragments of quartzite, schist, orthoclase- and plagioclase-felspars, micrographic granite, occasional bundles of mica, and chlorite. The grains are generally stained with iron oxides, which latter are also deposited in the cavities. The most interesting feature presented by these specimens is the frequent occurrence of quartz-grains which have undergone secondary growth. Rounded grains, darkened by inclusions, are surrounded by borders of clear transparent quartz, that have grown out to fit and interlock with neighbouring grains, whilst each border is in optical continuity with its turbid nucleus. In one case, which I have figured, traces of the crystalline faces, formed as free surfaces during the secondary growth of the crystals, are seen as parallel lines in the section (fig. 5). In the hand-specimen the

Fig. 5.

Secondary growth of quartz around a sand-grain. Minute inclusions show parallel lines of growth of the crystalline form. In grit from Indong, Kyŏng-sang Do.

faces of the crystals thus formed are recognized by the way in which they reflect the light from the plane-surfaces, like the so-called "crystalline sands" which were shown by Dr. Sorby, in 1880, to be produced in the same way by the secondary growth of quartz upon sand-grains which were fragments of original quartz-crystals †. The same thing has been shown by Mr. A. A. Young ‡, Dr. R. D.

* *Op. cit.* p. 867.
† Quart. Journ. Geol. Soc., Pres. Addr., vol. xxxvi. (1880).
‡ Amer. Journ. Sci. 3rd ser. vol. xxiii. (1881) p. 257, and vol. xxiv. p. 47.

Irving *, and Mr. Van Hise † to be the cause of the structure of certain sandstones and quartzites in the United States.

The peculiar effect produced by light reflected from the surfaces of these small quartz-crystals, somewhat resembling minute fragments of "Belleek" ware, might be due to the same cause which produces the characteristic appearance of Professor Harkness's mineral, cotterite ‡.

## VI. Summary.

Although the southern half of Korea may be looked upon as a distinctly hilly country, there are no mountains exceeding 3000 to 4000 feet in height; and these are, for the most part, rounded hummocks bounding rice-growing valleys and plains.

The rocks building up these hills are chiefly members of the group of crystalline schists and gneisses, with graphite, garnet, dichroite, and fluor occurring in considerable abundance; and the whole group forms probably a part of the great mass of Archæan rocks of north-eastern China, so well-known through the descriptions of Von Richthofen.

Stratified rocks of various kinds (shales, sandstones, grits, and conglomerates) lie unconformably on the schists in the south-eastern part of the peninsula, and are probably of Carboniferous age.

Through the crystalline schists and stratified rocks various igneous rocks have been erupted, and are now exposed as projecting dykes, or, in large masses, as bare, rounded hills and mountains. Amongst the results of igneous action granite is the most conspicuous rock. Biotite- and muscovite-granites are most widely distributed, and in places are cut by dykes of eurite (or "felstone") and veins of quartz and pegmatite. The more basic class of rocks is represented by diorites, propylites, andesites, basalts, dolerites, and gabbros (Prof. Roth). Interesting cases of the gradual passage between the so-called intermediate and basic rocks are found, and various stages in the devitrification and decomposition of andesitic lavas are represented.

There are now no active volcanoes, neither are there any known records of the occurrence of earthquakes. The only manifestation of the present activity of internal forces consists in the warm springs occurring in various parts of the peninsula.

There is a notable lack of mineral wealth in the southern part of Korea.

* Amer. Journ. Sci. 3rd ser. vol. xxv. (1883) p. 401.

† Bull. U.S. Geol. Surv. No. 8.

‡ 'On Cotterite, a new variety of Quartz,' Mineralog. Mag. vol. ii. (1878 p. 82.

## VII. Appendix.

Distances and principal Aneroid Readings made by Mr. Gowland between Söul and Fusan [as means of determining to some extent the topography of that part of the country, which is otherwise unknown].

| Date. | Name of place. | Distance in *li*. | Aneroid reading *. | Aneroid reading at highest point of journey on the date given. |
|---|---|---|---|---|
| 1884. | | | | |
| Oct. 1 ... | Söul .............................. | ...... | 29·85 | |
| " " ... | Kwachhön .............................. | 30 | 29 89 night. | |
| " 2 ... | " .............................. | ...... | 29 92 morning. | |
| " " ... | " Pass .............................. | ...... | ...... | 29·56 |
| " " ... | Yongin .............................. | 38 | 29·77 | |
| " " ... | " Pass .............................. | ...... | ...... | 29·59 |
| " " ... | Yang-ji .............................. | 36 | 29·56 | |
| " 3 ... | " .............................. | ...... | 29·69 | |
| " " ... | " top of plateau .............................. | ...... | ...... | 29·52 |
| " " ... | Pekkemmi .............................. | 30 | 29·84 | |
| " " ... | .............................. | ...... | ...... | 29·74 |
| " " ... | Chuksan .............................. | 30 | 29 85 | |
| " 4 ... | " .............................. | ...... | 29·84 | |
| " " ... | .............................. | ...... | ...... | 29·77 |
| " " ... | Yukei .............................. | 50 | 29·80 | |
| " " ... | , top of pass .............................. | ...... | ...... | 29·38 |
| " " ... | Eumsong .............................. | 30 | 29·57 | |
| " 5 ... | " .............................. | ...... | 29·57 | |
| " " ... | " top of pass .............................. | ...... | ...... | 29·34 |
| " " ... | Chhungju .............................. | 60 | 29·76 | |
| " 6 ... | " .............................. | ...... | 29·86 | |
| " " ... | " Pass .............................. | ...... | ...... | 29·36 |
| " " ... | Brambe .............................. | 50 | 29·50 | |
| " " | Mungyong Pass (highest point of journey) .......... | 20 | ...... | 27·93 |
| " " ... | Pushin .............................. | 10 | 29·24 | |
| " 7 ... | " .............................. | ...... | 29·29 | |
| " 8 ... | " .............................. | ...... | 29 30 | |
| " " ... | Mungyong .............................. | 10 | 29·59 | |
| " " ... | .............................. | ...... | ...... | 29·61 |
| " " ... | Yuko .............................. | 40 | 29·71 | |
| " 9 ... | " .............................. | ...... | 29·78 | |
| " " ... | Hamchhang .............................. | 20 | 29·94 | |
| " " ... | Sangju .............................. | 40 | 30·04 | |
| " 10 ... | " .............................. | ...... | 30·17 | |
| " " ... | .............................. | ...... | ...... | 29·28 |
| " " ... | Sönsan .............................. | 70 | 30·16 | |
| " 11 ... | " .............................. | ...... | 30·14 | |

* When two readings are given at one place this indicates that the first was made in the evening and the second before resuming the journey on the following morning.

APPENDIX (*continued*).

| Date. | Name of place. | Distance in *li*. | Aneroid reading. | Aneroid reading at highest point of journey on the date given. |
|---|---|---|---|---|
| 1884. | | | | |
| Oct. 11 ... | Haiphyong ...................... | 20 | 30·08 | |
| " 12 ... | " ...................... | ...... | 29·98 | |
| " 13 ... | " ...................... | ..... | 29·98 | |
| " " ... | ...................... | ...... | ...... | 29·81 |
| " " ... | Indong ...................... | 25 | 29·97 | |
| " " ... | ...................... | ...... | ...... | 29·71 |
| " " ... | Tawŏn ...................... | 40 | 29·39 | |
| " 14 ... | " ...................... | ...... | 29·33 | |
| " " ... | ...................... | ...... | ...... | 29·18 |
| " " ... | Chilgok ...................... | 25 | 29·86 | |
| " " ... | Taiku ...................... | 20 | 30·04 | |
| " 15 ... | " ...................... | ...... | 30·11 | |
| " " ... | ...................... | ...... | ...... | 29·98 |
| " " ... | Kyŏngsan ...................... | 30 | 30·05 | |
| " 16 ... | " ...................... | ...... | 30·14 | |
| " " ... | ...................... | ..... | ...... | 29·41 |
| " " ... | Chhongdo ...................... | 50 | 29·98 | |
| " " ... | Unchhŏn ...................... | 35 | 30·21 | |
| " 17 ... | " ...................... | ...... | 30·21 | |
| " " ... | Milyang...................... | 20 | | |
| " " ... | Undon ...................... | 25 | 30·26 | |
| " 18 ... | " ...................... | ...... | 30·31 | |
| " " ... | Yangean ...................... | 35 | 30·29 | |
| " " ... | Pumasa Temples ............... | 30 | 29·16 | |
| " 19 ... | " " ............... | ...... | 29·23–29·19 | |
| " " ... | Tong-nai ...................... | 23 | ...... | |
| " " ... | Fusan...................... | ...... | 30·26 (sea-level) | |
| " 20 ... | " ...................... | ...... | 30·16 " | |

## DISCUSSION.

Prof. JUDD spoke of the value of Mr. Gowland's geographical and geological discoveries, and the enthusiasm with which Mr. Holland had applied himself to the work of examining the specimens brought home. He considered that the work would prove an important contribution to science. Several points about which difficulties had arisen by examination of European rocks had light thrown upon them by the Korean specimens.

The PRESIDENT felt that the Society would agree with him in considering the Geological Survey of India fortunate in securing a petrologist like Mr. Holland.

15. *The* GEOLOGY *of* BARBADOS. By A. J. JUKES-BROWNE, Esq., F.G.S., and Prof. J. B. HARRISON, M.A., F.G.S. (Read February 4, 1891.)

Part I.—THE CORAL-ROCKS OF BARBADOS AND OTHER WEST-INDIAN ISLANDS.

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## § 1. INTRODUCTION.

SEEING that Barbados has always been a station for our West-Indian forces, and that it has for some time been the first place of call for the Royal Mail steamers, it is somewhat strange that no adequate account of the geology of the island has ever been published, especially as it is one of the most healthy of our West-Indian possessions and offers few physical difficulties to the explorer.

The earliest notice on Barbados is a short paper by Dr. J. Skey *, but this gives very little information. Ehrenberg in 1854 described the Microzoa obtained from the white earths of Barbados, and the Radiolaria have since become familiar to microscopical students; but the true geological position of these earths has never been made known.

So far as we can learn, the only geological description of the island is that given by Sir Robert Schomburgk in his "History of Barbados" (1848). So far as it goes, and considering the date at which it was written, Schomburgk's description is a good one. He describes the rocks under two heads: (1) Coral Limestone, (2) Siliceous rocks.

His account of the Coral Limestone is fairly complete and accurate; he explains the phenomena which it presents by a gradual but discontinuous upheaval of the area, and truly remarks that the structure of the island offers several features which are difficult to reconcile with Darwin's theory of coral-reefs.

For the siliceous rocks he proposes the name of "Scotland Formation," because the area in which they occur is known as the Scotland District, and he includes the Radiolarian marls under this head,

* Trans. Geol. Soc. ser. i. vol. iii. (1816) p. 236.

writing of them as if they were interstratified with the clays and sandstones which are the prevalent rocks of that district. Our examination, on the contrary, has led us to conclude that they are entirely distinct from and newer than these clays and sandstones, though the two series are often brought into juxtaposition by means of powerful faults.

In accordance with the ideas prevalent at the time he wrote, Schomburgk refers the contortions of the rocks and the upheaval of the island to a volcanic convulsion, and regards the gullies which traverse the Coral Limestone as having originated in a series of cracks produced by this volcanic convulsion. From this view, as might be expected, we most unequivocally dissent.

Since the publication of Schomburgk's book, no geologist seems to have examined the island. Prof. Duncan's paper on West-Indian Corals * (1863) will be referred to in the sequel. Meanwhile it will suffice to say that we cannot accept his view that the Coral Limestone of Barbados is of Miocene age.

Mr. Lechmere Guppy, in his paper on the West-Indian Tertiaries † (1866), refers briefly to Barbados, and points out that no extinct species of Mollusca have been recorded from any of its Coral Limestones.

Alexander Agassiz, in "The Three Cruises of the 'Blake'" (1888), makes several references to Barbados, but he did not make any personal explorations on the island, and has unfortunately been misled into stating that it is "a volcanic cone entirely surrounded by coral terraces which completely hide the cone" ‡; and again, "The trachytic cone forming the base upon which the successive terraces of Barbados have been elevated is seen to crop out on the surface in the north-east part of the island" §.

As no such mass of trachytic rock had been seen by us, and as we had not found even so much as a dyke of volcanic rock in any part of the island, we wrote to ask Prof. Agassiz what ground he had for his statements. In reply he explained that they were made on the authority of a gentleman in Bridgetown who showed him specimens of trachytic rock obtained from the north of the island, and who assured him that the rock existed *in situ*; but he admits that as he did not visit the locality he ought perhaps to have been more guarded in his statements.

We believe the mistake originated in the following way:—Fragments of trachytic rock do occur on the surface-soil in many places, and some of them are nearly as large as a man's fist, but we believe that they have all been imported into the island. Raw guano brought from the islands off the northern coast of South America has been used as a manure for many years past, and fragments of volcanic rocks as large and even larger than a man's fist

* Quart. Journ. Geol. Soc. vol. xix. p. 406.
† *Ibid.* vol. xxii. p. 570.
‡ Bull. Mus. Harvard Coll. p. xix; see also p. 63.
§ *Op. cit.* p. 79.

are by no means rare in this material, as one of us can testify from personal experience. The specimens shown to Prof. Agassiz were doubtless picked up on the island, and probably that is all his informant meant by assuring him that they occurred "in place" *.

As will be seen from our sections, the basal part of the island everywhere consists of stratified rocks, chiefly dark sandy clays and sandstones; for these we propose to retain Schomburgk's name of "Scotland Rocks." Overlying these and resting unconformably upon them is a series of light-coloured and chalky-looking deposits, some of which are calcareous and others are mainly siliceous; they are all of deep-sea origin, and include the well-known Infusorial or Radiolarian earth.

* There is a collection of stones in Bridgetown which is probably that seen by Prof. Agassiz, and it contains one piece of trachyte; this looks like a piece of a large pebble, and is labelled as coming from Canefield, an estate which one of us carefully examined without finding any rocks differing from those seen elsewhere.

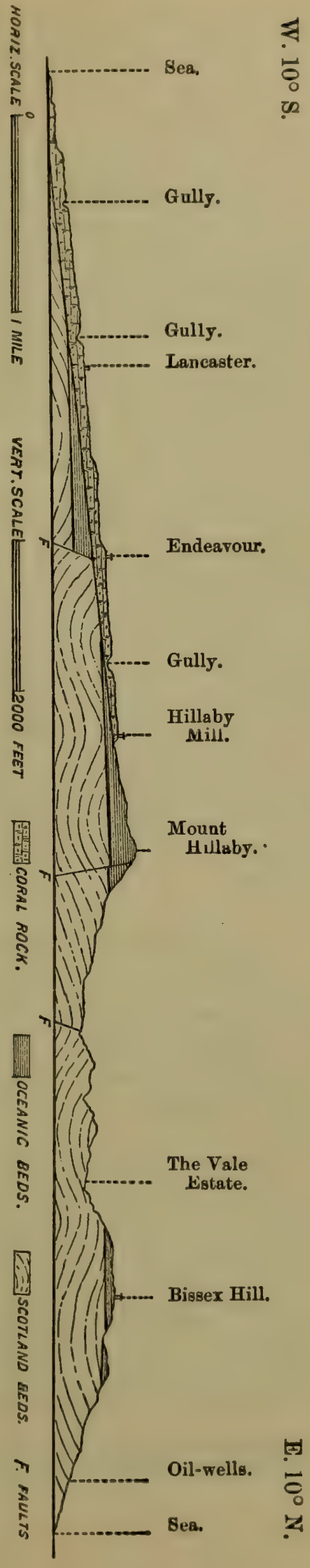



Fig. 1.—Section across the Island through Mount Hillaby.

They may be called the "Oceanic Series," or, as Colonel Feilden has suggested, the "Thalassic Series" *.

The Coral Limestone which forms so large a portion of the surface of the island is only a crust or covering of very variable thickness, and the true structure of the island is plainly visible to any one who walks along the central heights, where the Coral Limestones terminate in scarped cliffs and promontories, from beneath which the Oceanic beds crop out and form in some places an undulating plateau and in others a steep slope. The Scotland beds emerge at a lower level (except where they are faulted up), and form the rugged hills and valleys of the district from which they take their name.

The island is nearly surrounded by growing coral-reefs, which are of special interest in connexion with the reefs that have been raised above the sea-level.

A general account of the geological structure of the island, of its physical history, surface features, soils, and economic products, has been printed in the "Explanation of the Geological Map of Barbados" which we prepared, and which has been published at the expense of the Barbadian Legislature. In the following pages we propose to give a more detailed account of the coral-rock of Barbados, with some notice of similar rock in other West-Indian islands and of the inferences that may be based on the existence of these raised reefs. In a future paper we propose treating more fully of the Oceanic deposits and of the conditions under which they were formed.

The figure on the preceding page illustrates the general structure of the island, being a section through Mount Hillaby, which is the highest summit, and across the widest part of the Scotland District. Any other section across the island would show a larger surface-area of coral-rock.

## § 2. The Coral-reefs now growing.

As raised coral-reefs cover so large a portion of the island, and as the lower or most recent of the terraces must have been built up under nearly the same conditions as those which now guide and limit the form of the modern reefs, it is clear that any facts relating to the latter will assist us in comprehending the features presented by the former.

Any facts relating to the form of the reefs now growing round Barbados will have a further interest, because the island itself affords proof of great and long-continued upheaval without the slightest sign of subsequent subsidence. It is not of volcanic origin, as so many coral-islands are, and has never been a focus of eruption, consequently there is the less likelihood that its elevation was followed by subsidence. There are therefore strong grounds for inferring that the recent coral-growths round the island have been formed in an area which was either stationary or was possibly for a

* Col. Feilden has given an accurate epitome of the geology of the island in a paper on the 'Birds of Barbados,' Ibis, Oct. 1889.

time slowly rising, and that none of the phenomena which they exhibit are in any way due to movements of subsidence.

The exposed surface of a fringing coral-reef has so often been described that we do not propose to give any account of this aspect of the reefs, for, after all, little can be learnt from such exposures as to their mode of growth. Less attention has been paid to the submarine profiles of the outer slopes of such reefs and to the depths to which coral-growths extend beneath the waters of the sea. We offer some remarks on these points, our information being chiefly derived from the large Admiralty map of the island on a scale of $3\frac{5}{8}$ inches to a mile. In most cases personal exploration would be necessary, but the soundings on this map are so multiplied that it is easy to plot a profile of the seaward slope from any point on the coast of the island, and the records of the nature of the bottom are sufficiently numerous to yield some important inferences when checked by such information as we could obtain regarding the nature of the coral-growths.

Coral-reefs are found all round the island except off a portion of the north-east coast fronting the Scotland District. A few patches of coral occur near the shore north-west of Consett's Bay, but the continuous reefs cease opposite Bath estate, and from there to the Landlock or Corbet's Bay all soundings over 5 fathoms show sand or mud. The growth of coral along the east coast as far as Consett's Bay proves that the absence of reefs farther north is not to be attributed to the force of the surf which breaks on this coast, for all parts of it are equally exposed.

We have little doubt that the absence of coral along the tract above indicated is due to frequent invasions of muddy water, for after heavy rains the watercourses which drain the Scotland District are converted into torrents that pour tons of muddy water into the sea and discolour the sea-water for a distance of a quarter to half a mile from the shore. After describing one of these sudden floods, Mr. J. H. S. Moxley * says:—"The effect of the freshet upon the colour of the sea was much greater than even those who had seen its volume could have supposed. The dazzling whiteness of the foam of the breakers was changed in the first hour of the violence of the torrent to an inky hue, and afterwards to a sullen mud-colour which remained for two or three days, but growing gradually clearer, while an unpleasant earthy odour arose from the sea-shore, strewn as it was with the débris brought down by the flood."

Such floods, even if they occurred only once a year, would be quite sufficient to prevent the growth of coral, though the constant discharge of clear and pure fresh water which takes place along the western coast does not seem to interfere at all with the coral-growths, except where it produces a sand-moving current.

We will now deal with the submarine contours round the island, and commence at the place above mentioned opposite Bath estate on the eastern coast. Along a line drawn out to sea due N.E. from

* 'Guide to Barbados,' p. 107: Sampson Low & Co.

Bath there is no reef-coral beyond the three-fathom line, which is about 590 yards from the shore; from this line there is a steep slope to 13 fathoms, and then a plateau gradually deepening to 24 fathoms, beyond which is another steep slope down to 100 fathoms. This is the typical contour of the coast opposite the Scotland District, and the line of 24 fathoms is nearly parallel to the line of 100 fathoms, showing the regularity of the profile. In the shallow water down to 24 fathoms the bottom is generally sand; beyond that it is generally mud.

The profile above described is shown in fig. 2 by the lower line AB, while the upper line is a profile drawn in the same direction half a mile south of the first through the beginning of the coral-plateau. A comparison of the two profiles at once suggests that the coral-reef has been built upon the sand-plateau shown in the lower profile, and that it was limited by the seaward extent of this plateau; further, that the coarse sand which extends in the upper profile to the line of 60 fathoms is a product of the waste of the coral-reef, and we may infer that, if any part of this were raised to within 25 fathoms of the surface, reef-corals would begin to grow upon it. So close together are the two lines of section that we may even take the distance between the two outlines as giving some guide to the thickness of reef which has here grown up on the sand-plateau; it is from 10 to 12 fathoms, *i. e.* 60 to 70 feet.

From this locality the submarine coral-plateau extends round the eastern part of the island. It varies in width, but always has a steep outer slope, plunging down from 10 to 20 or 25 fathoms. Opposite Kitridge Point the plateau broadens out and becomes at the same time divisible into two stages or shelves, an inner one covered by 2 to 4 fathoms of water, and an outer one covered by 6 to 10 fathoms (see fig. 3, upper line).

South of this two new features commence, and both are very noteworthy. The first is, that a part of the reef within the four-fathom line rises to the surface and forms what is known as the Cobbler's Reef, which, with other similar reefs, forms a nearly continuous outer reef along the south-east coast of the island as far as South Point. The Cobbler's Reef at its north-east end has a breadth of more than half a mile exposed at low water, but it narrows to the south-west, and, though the reef itself is a continuous ridge, there are places where it does not quite reach the surface, leaving gaps covered by one or two fathoms of water. Between this outer reef and the discontinuous shore-reefs there is a shallow channel having an average depth of 3 or 4 fathoms; it is very wide near the eastern end of the island, where the coral-growth seems to find its maximum development, and extends to a distance of a mile and three quarters from the shore.

The second feature above alluded to is the appearance of a channel in what may be called the nine-fathom ledge, *i. e.* the lower coral-shelf on which the water has an average depth of 9 fathoms. This channel commences opposite the northern end of the Cobbler's Reef, and becomes both wider and deeper to the south-west, leaving

Fig. 2.—*Profiles of submarine terraces near Bath.*

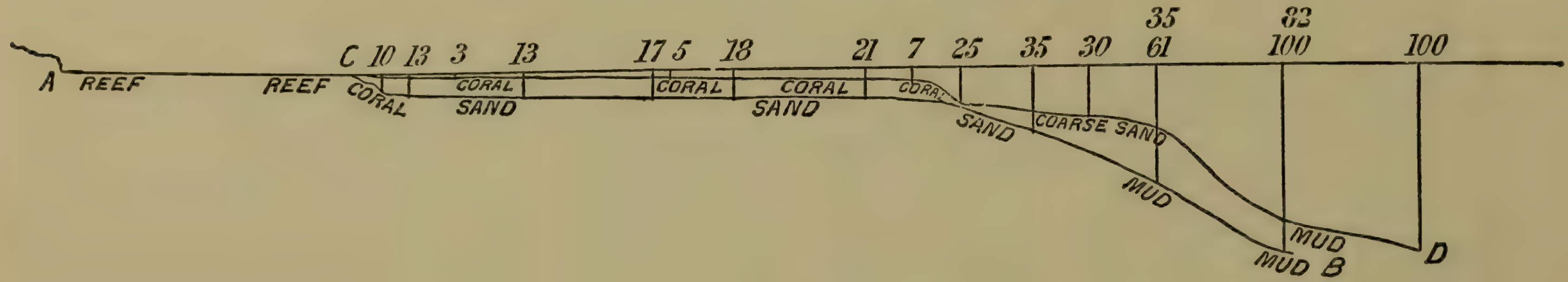
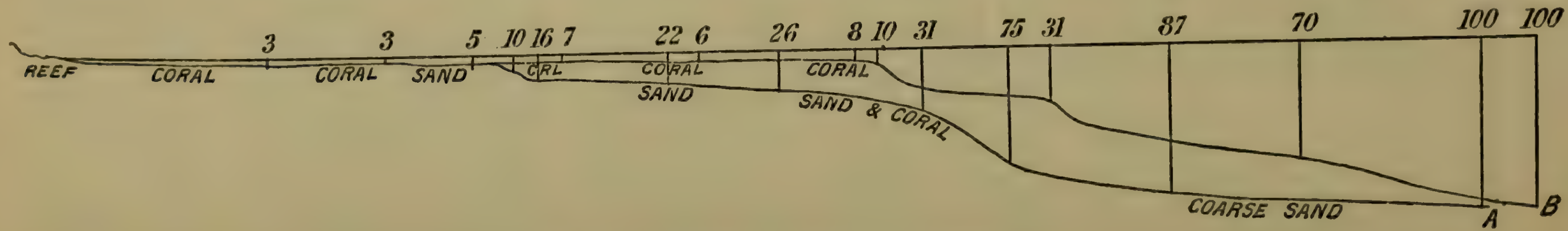



Fig. 3.—*The upper horizontal line represents the sea-level. The intermediate line to* B *represents profile from Kitridge Point to E.N.E. The lower line to* A *represents profile from near South Point to S.W.*




NOTE.—Numbers indicate depth in fathoms.

the outer part of the nine-fathom ledge to form a narrow ridge or wall which rises steeply on both sides from depths of 18 or 20 fathoms (see fig. 4). This submarine ridge is roughly parallel to the outer reef above mentioned, and is perfectly continuous for a distance of about twelve miles, ending nearly opposite the termination of the surface-reef off the south point of the island; it is in fact a submarine barrier-reef, for if it was built up to the surface there would be a navigable channel inside it.

This submarine ridge or wall appears to consist everywhere of growing coral, and the usual depth of water above it is 8 or 9 fathoms, but in some places there are only 6 fathoms; as limited by the ten-fathom line its top is about 100 yards broad, varying from 80 to 150 yards. On the outside there is always a steep slope, and sometimes depths of 18, 20, or 22 fathoms are marked close to the ten-fathom line on the chart, with depths of 25 to 30 fathoms within 100 yards. On the inside the slope appears to be equally steep, often dropping from 10 to 20 fathoms in a few rods' distance, and in one case 23 fathoms is marked close to the inside wall.

The average depth of the channel inside this submarine wall is 20 fathoms, and its average width about half a mile; the bottom is nearly everywhere sand, sometimes fine and sometimes coarse, which is no doubt calcareous coral-sand derived from the outer fringing-reef which comes within the constant action of the breakers. On the inner side of this channel the bottom rises rapidly to the ten-fathom line, from which there is a more gentle slope to the four-fathom plateau.

From the above description, and from the profiles in fig. 4, it is evident that the Cobbler's Reef is a portion of the four-fathom plateau which has grown up to the surface, and that the submarine barrier-reef is a ridge-like continuation of the nine-fathom plateau which exists to the north of Kitridge Point. Moreover, as the development of the submarine barrier commences opposite the point where the Cobbler's Reef begins, it would seem that the one is in some way connected with or dependent on the existence of the other.

Prof. Semper has sought to explain the conformation of growing coral-reefs by the influence of currents, and states "that wherever constant and deep currents impinge on a coast at an angle, the reef will inevitably grow upwards perpendicularly if the force of the current be sufficient"*. Now the current of the Gulf-stream impinges on the eastern coast of Barbados, the local currents forking against the eastern point, and running at $1\frac{1}{2}$ knots an hour both to the N.W. and the S.W.; if therefore the peculiar conformation of reefs along the south-east coast were due to the action of currents, it should be the same along the north-east coast, where for some distance similar conditions prevail, the current in both cases impinging at an angle and having the same velocity. This explanation will consequently not apply to Barbados.

* 'Animal Life,' 3rd edition, p. 265, Internat. Science Series.

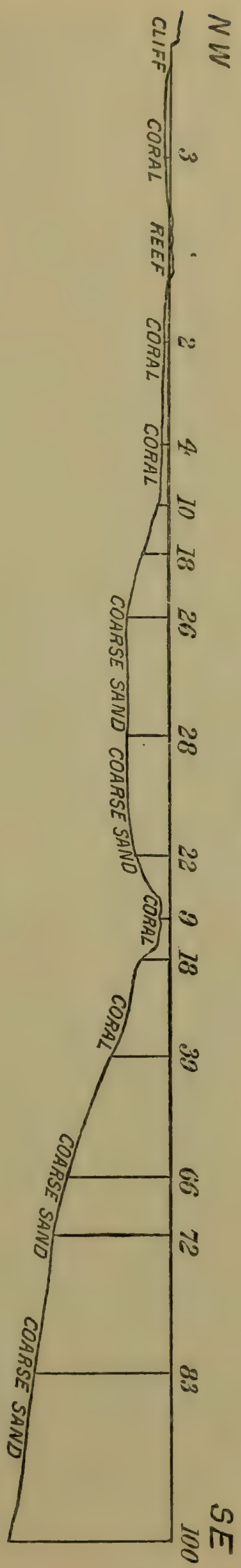



Fig. 4.—*Submarine profile on south coast to S.W. from near Long Bay.*

The "reef" in this figure is Cobbler's Reef.

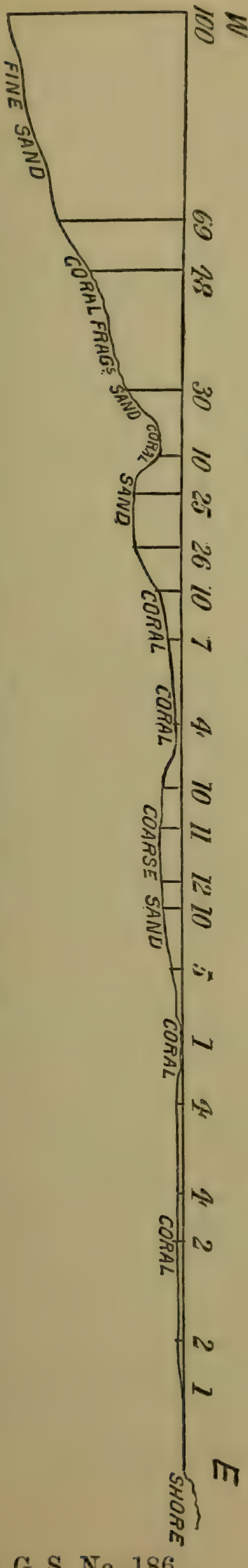



Fig. 5.—*Submarine profile on west coast from near Spring Garden.*

Note.—Numbers indicate depth in fathoms.

Dr. H. B. Guppy, in his excellent and suggestive paper on the Coral Reefs of the Solomon Islands *, has offered an explanation of the formation of outer reefs which can be applied to the Barbadian reefs, and explains the relation of the submarine wall to the surface reef. The features of the Solomon-Island reefs, according to his description, resemble those of the Barbados reefs. Their submarine profiles often show two terraces, first a ledge from the edge of the shore-reef to a depth of 4 or 5 fathoms, then a steep declivity to 20 fathoms, below which is a broad plateau gradually sloping to 25 fathoms, and ending in a steeper slope to deep water. Dr. Guppy's soundings showed that at the base of the first declivity there was always coral-sand and débris, which prevented the growth of living coral, but that farther out on the plateau beyond this sandy zone living coral again occurred. He points out that where a shore has such an outline the conditions favour the formation of a *barrier-reef*, because, if the outer part of the lower plateau or terrace lies within the depth in which reef-building corals can flourish, they will grow freely there and will be forced to grow upward by the contiguity of deep water on one side and sand on the other; in this way an outer barrier-like reef may be initiated, separated from the shore-reefs by a sand-covered channel.

Applying this explanation to Barbados, we find that where no part of the inner coral-shelf rises to the surface, the lower plateau is continuous, and only small patches of sand occur on it; but where reefs like the Cobbler's Reef exist, the action of the breakers leads to the formation of a débris-slope below them, and yields a deposit of coral-sand which prevents the growth of coral; the current impinging on the reef probably helps to make this sand-bank a narrow one by driving the sand along the slope; outside the sandbank the water is still shallow enough for the growth of reef-corals, and consequently they have grown upward in the form of a ridge or barrier, the outer edge of which is limited by the depth of the water.

One reason for the vigorous growth of coral at this eastern end of the island is probably that the polypes find a superabundant supply of food in the microzoa brought by the Gulf-stream, which here first impinges on the island.

The supposition that such a shelf or plateau extending to 25 or 30 fathoms did exist along this shore before the growth of the coral is confirmed by the contour of the sea-floor beyond the termination of the outer reefs. The lower line in fig. 3 (p. 203) is a profile running S.W. from the shore near South Point. The soundings in this direction from 20 to 30 fathoms all prove sand or sand and coral fragments, and the conditions do not appear to be favourable for coral-growth; so that we may infer that the profile represents the original contour slightly masked by sandy deposits. It is, however, difficult to understand wherefore the two lines of reef should end off so suddenly, though this abrupt termination

* Proc. Roy. Soc. Edinb. 1885–86, p. 857.

would appear to be connected with the set of the currents, and possibly with the supply of food. The main current is directed westwards, while the shore recedes northwards round Oistin's Bay. As a matter of fact, very little coral grows in this bay, the bottom being everywhere marked as sand, except at a few depths between 30 and 60 fathoms where coral is recorded (probably broken fragments or else species which are not reef-builders).

The case is much the same in and outside Carlisle Bay, at the south-western corner of the island, for, although coral is recorded on the chart at many places down to 45 fathoms, it is only here and there in the shallower parts that patches of true coral-reef occur, most of the coral indicated, and especially in the deeper parts, being isolated and not reef-building species *. The water increases gradually, though irregularly, to 35 or 40 fathoms, and there is then a steep slope down to 60 fathoms, with a bottom of coarse sand. The submarine plateau is therefore continued, but it would seem as if the top of the slope were here at a greater depth than farther east, being at about 35 instead of 25 fathoms, and consequently too deep for the growth of reef-building corals.

The plateau above mentioned extends northwards for two or three miles, and opposite Spring Garden there is a group of shoals upon it which have interesting relations. An upper terrace (at an average depth of 3 fathoms) reaches out some distance from the shore, but is indented by several bays and channels which are apparently connected with the submarine outlets of subterranean freshwater streams, for in several places water can be seen bubbling up through the sand at the bottom. From this coral plateau several small reefs, known as the Pelican Shoals, rise to within a fathom of the surface; outside it there is a channel with depths of 10 to 14 fathoms, and beyond this two isolated reefs which rise to within 7 or 8 fathoms, and in some places even less. Beyond these the water deepens rapidly to 25 fathoms, and the bottom is coarse sand (see fig. 5, p. 205). The existence of these channels and the growth of the reefs seem to be due to the distribution of the sand by the currents from the submarine springs; the arrangement, in fact, may be explained on the supposition that when reef-corals are prevented from spreading laterally by the encroachment of sand they grow vertically and build up either bosses or wall-like ridges, according to the shape of the area which is not invaded by sand. North of this locality there is a change in the submarine profile; the extent of shallow water is much less, the two terraces limited by the three- and the eight- or nine-fathom lines are well-marked, but narrow, and there are steep slopes from 10 to 40 or 50 fathoms. These conditions continue along the greater part of the western coast, and are evidently due to the steep inclination of the original landward slope.

The only notable interruption of this conformation is opposite Holetown, where there are two deep inlets in the eight-fathom

* For this information we are indebted to G. F. Franks, Esq., M.A., F.G.S., of the Harrison College, Barbados.

plateau, and two outer reefs rising to within 7 fathoms, separated from this plateau by channels of 10 to 20 fathoms deep. The inlets have a bottom of sand and mud, which has doubtless been brought in from the land during the occasional heavy rains which are common in Barbados. Several gullies converge at Holetown, and as their sources are on the Hillaby range at elevations of 900 to 1000 feet, and only five miles distant, their channels have a rapid fall and they probably have brought down large quantities of detritus, the influx of which must have affected the growth of the coral. There is, moreover, a permanent flow of fresh water from the Holetown outlet.

North of Holetown the submarine profiles are uniformly steep till we reach Maycock's Bay, in the extreme N.W. of the island. Here again the four-fathom line runs out from the shore, and there is a wide shallow plateau extending for about four miles to the north-east. From this several reefs rise to the surface, and are exposed to the constant action of the breakers. These are the Harrison Reefs, and they are comparable to the Cobbler's Reef at the opposite end of the island. Consequently it is interesting to find a repetition of the same phenomena outside the Harrison Reefs, namely a lower plateau covered by from 7 to 9 fathoms of water, and traversed along the greater part of its length by a channel which is from 11 to 13 fathoms deep; so that the outer part of the plateau runs out as a wall-like ridge parallel to the inner reefs, forming a submarine barrier-reef like that off the south-east coast. These features cease at the northern end of the island, and the submarine profile gradually changes to a continuous slope with very little coral-growth. The extreme northern and north-eastern coasts are backed by ranges of rugged cliffs, with promontories and detached rocks, features which clearly indicate erosion and recession of the coast-line.

From the above account of the coral-reefs that are now growing round the shores of Barbados, we learn several facts which throw light on the structure and conformation of the raised reefs and limestones that cover so large a part of the island. In the first place it would appear that reef-corals can certainly build up from a depth of 25 or 30 fathoms, so that, supposing they continued to flourish for a sufficient length of time without any movement of the land, they might build a reef which would have a thickness of 180 feet.

Secondly, we find that there are always deposits of coral-débris and calcareous sand in front of the lowest reefs; so that, if the area were elevated, this would come within the limit of reef-coral growth and would form the foundation of a new reef. In this way 20, 30, or even 50 feet of limestone-material containing coral fragments may be formed before any actual reef-growth takes place upon it; but when raised this would differ from coral-reef rock only in the absence of large masses of solid coral.

Thirdly, the prevalent outline of the submarine profile is that of shelves or terraces, varying in width according to the slope of the

bottom; sometimes there is only one shelf, reaching gradually to 10 fathoms with a steep slope to 25, sometimes two or even three shelves, especially along the western coast. It would appear, therefore, that the terrace-like appearance of the raised reefs may be partly due to the original conformation of the reefs before upheaval, and not always or entirely to erosion during pauses in the upward movement. In other words, the outer slopes of the raised reefs may sometimes be the unmodified edges of the reef-plateau, though in many cases, as we shall see, the scarps exhibit evidence of modification and erosion.

## § 3. The Raised Reefs or Coral-rocks.

(a) *General Description.*—Six-sevenths of the surface-area of Barbados, that is 144 out of 166 square miles, consist of coral-rock or limestone formed largely from the débris of corals. This rock may be regarded as a sheet or mantle of recently-formed limestone covering and enveloping the greater part of the dome-shaped mass of the older rocks. It must not, however, be viewed as a single even and continuous sheet, for it really consists of a number of separate stages or platforms built up one around the other as the island slowly rose from the sea. Each of these platforms was once a fringing coral-reef like that which now surrounds the greater part of the island, and they now form a succession of steps and terraces of greater or less width, rising one above another from the sea-level to a height of nearly 1100 feet in the centre of the island, each step in the ascent being of slightly older date than the one below.

The first noticeable feature is that these terraces are not all subsidiary to one centre. The principal system of terraces conforms to the central ridge of high elevation which curves round the highest part of the Scotland District between Mount Hillaby and Castle Grant, this system descending by a series of slopes and plateaux from levels of over 1000 feet to a level of about 150 feet on the northern, western, southern, and south-eastern sides. It is limited on the south by the broad valley or depression that extends across the southern part of the island from Bridgetown to the Crane.

South of this there is a smaller independent system of terraces forming what is known as the Christchurch Ridge. No part of this ridge is more than 400 feet above the sea, and all that portion which is over 300 feet is broken up into a set of irregular east and west ridges; these are concentrically surrounded by a series of lower terraces.

The newest terraces, or those below 150 feet, having been formed after the union of the two island-centres, are in consequence continuous round the whole western and southern borders of the present island, exhibiting a close parallelism to the present line of coast.

There is a second ridge at a higher level, which is nearly isolated, and presents some features which are analogous to those

of the Christchurch Ridge. It is known as Golden Ridge, and has an elevation of from 700 to 877 feet; the only ground of equal height lies to the north of it, but is divided from it by a broad valley which is nowhere much above 700 feet.

The rise from one terrace to another varies greatly in vertical height, being sometimes only a sloping bank 9 or 10 feet high, sometimes a very steep slope for 50 or 100 feet, and at others a line of cliffs. There are in fact minor and major terraces, the former being only traceable for a certain distance, though this is often several miles, while the latter form bold features that are continuous through the coral area.

The southern ridge has six well-marked terraces, the lower steps being very conspicuous from the sea on the southern side. Six terraces at nearly corresponding heights can be traced along the eastern part of the island north of Bridgetown, the last ending in a slope which rises rapidly from 400 to 500 feet, and is one of the most marked features in the island. Above this there are at least five terraces, the highest being between 900 and 1000 feet, and there are other intermediate steps which are not so continuously traceable. The surface of the terraces is seldom level, but undulates, and often slopes gently outward towards the sea; they are also traversed by dry valleys or gullies which radiate from the central heights of the island, and terminate either near the coast or in the broad central valley along which the railway is carried.

Where the step or rise from one terrace to another passes into a line of cliffs there are sometimes caves which appear to have been excavated by wave-action. The old shore-lines in fact reproduce the variations in the present shore-line of the island, which is in some places only a sloping beach of coral-fragments banked against a raised reef, and in other places is a line of cliffs from 20 to 60 feet high, exhibiting all the usual phenomena that are due to marine erosion.

The parallelism of the lowest terraces to the present coast-line has been mentioned, but it is not entirely confined to them, for the older and higher reefs up to at least 600 feet have the same parallel trend, except of course where they are deflected into the transverse valleys; and it is noticeable that where the modern coast presents a line of cliffs the terraces behind them rise from similar cliff-lines or from very steep slopes. These facts seem to show that but little, if any, alteration has taken place in the direction of the marine currents or of the prevalent winds since the time when the formation of the higher terraces began.

(b) *Thickness.*—From the manner in which these successive platforms have been constructed, it follows that the thickness of the coral-rock of which they consist must vary greatly in different places, and this we find to be the case. The greatest thickness will generally be found near the outer margin of each raised reef, and its least thickness will be at the foot of the succeeding slope; but there are many exceptions to this rule, in consequence of the uneven surface on which the reefs have been built.

In many places banks of coral-sand and débris appear to have been formed outside a growing reef, and to have accumulated to a greater or less thickness before any true coral-reef grew upon them. Such detrital rock is frequently, if not always, found at the base of the coral-limestone, and its existence will account for the total thickness of this limestone being in some cases greater than the depth of water in which it is generally supposed that reef-building corals can begin to grow.

So far as we have been able to ascertain, there are not many localities where the thickness of coral-rock exceeds 200 feet. It is generally less than this amount, but does in some places appear to reach a depth of 230 feet; indeed in one place, namely Bowmanston, it is 260 feet, this being the measured depth from the surface at the mouth of the well down to the floor of the cavern into which the well opens, and it is known that the cavern is excavated in coral-rock.

For the following information relating to the depth of the coral-rock in different places, we are indebted to the courtesy of E. Easton, Esq., C.E., F.G.S., the particulars having been obtained from borings made for the Barbados Water-Supply Company.

A boring made in the gully near Lightfoots, in the parish of St. John's, was carried through coral-rock for 103 feet, passing then into red clay, and finally into Radiolarian earth 18 feet lower down; this gully itself cuts about 130 feet into coral-rock, so that the total thickness of the rock below the general surface of the ground must be 233 feet, the height of the ground above the sea being 552.

Another boring made in the bottom of the gully near Byde Mill, in the same parish, began at a level of 349 feet above the sea, the gully itself being at least 100 feet deep; the depth of the boring was 117 feet, and was still in coral-rock, the thickness of which is here, therefore, more than 217 feet.

It is noticeable that both Lightfoots and Byde Mill are near the border of a plateau, and consequently along a line where we might expect the reef-rock to be thick and to be based on coral-sand.

In Cole's Cave gully, on Walk's Spring estate, about six miles N.N.E. of Bridgetown, the level of the gully-floor is 685 feet above the sea, the level of the stream in the cavern below is 576 feet, and the level of the road at the edge of the gully opposite the cave about 752 feet. Here, therefore, there is at least 176 feet of coral-rock, and probably more in some places a little distance from the edge of the gully.

A boring in the gully between Rock Dundo and Zion Hill in St. James's parish reached Radiolarian earth at 41 feet from the surface and at a level of 263 feet above the sea, while the road along the top of the gully is 400 feet above the sea, so that the rock here is 137 feet thick. Moreover, to the east of this spot there is a very steep slope or escarpment, the top of which is 600 feet above the sea, and though the subterranean water-level probably rises, a section constructed for us by Mr. Hucklebridge (from data in Mr. Easton's office) shows that it is 250 feet below the surface of the

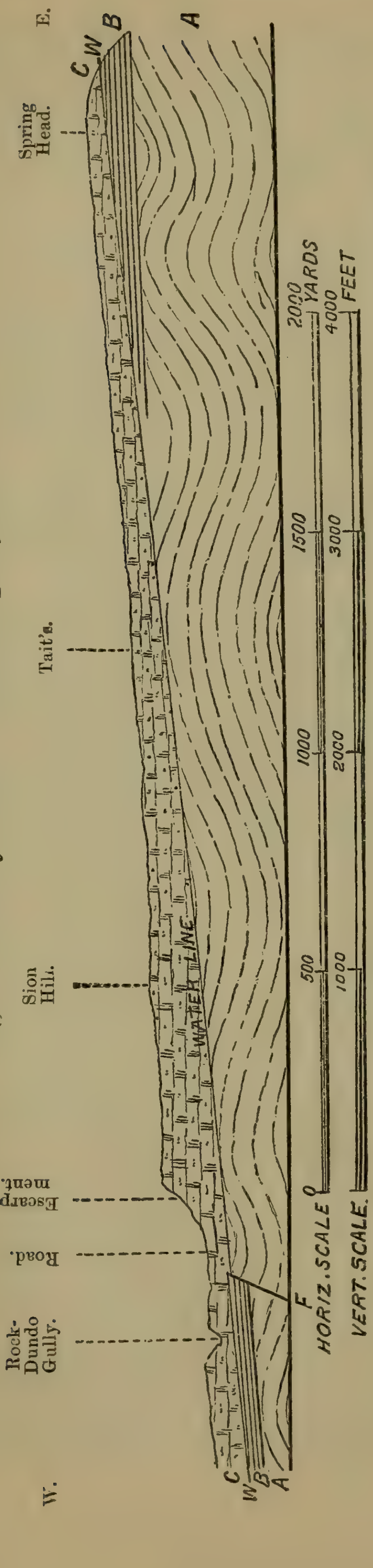



Fig. 6.—*Section from Rock Dundo to Spring Head.*

A. Scotland beds. B. Oceanic deposits. C. Coral-rock. W. Water-level. F. Supposed fault.

higher plateau, and this thickness is probably all coral-rock (see fig. 6).

Farther north a boring was made in the gully which runs between Mount Brevitor and Pleasant Hall, at a spot which is about 80 feet below the surface of the ground near the edge of the gully; the boring was carried through coral-rock, going through a cave at 116 feet and the base of the coral at 130 feet; the total thickness of the rock at this place appears therefore to be at least 210 feet.

Lastly, we ascertained that the well at Nicholas Abbey, near Mount Stepney, is 170 feet deep, and was dug entirely through coral, the water at the bottom being probably held up by the Scotland clays which crop out below Mount Stepney.

(c) *Internal Structure of the Coral-rock.*—Excellent opportunities of examining the coral-limestones are afforded by the cliffs on the southern coast, by the numerous quarries and road-cuttings, and by some of the steep slopes where the rock is bare and weathered.

The rock varies considerably in structure and in hardness even on the same level or terrace, but its usual character at levels below 300 feet is that of a rough whitish coarse-grained limestone, sufficiently compacted to stand in cuttings and quarries with a vertical face, but so little indurated that it can often be cut with a saw. Some portions of it are so soft, loose, and earthy that they can be dug out with a spade,

and this variety is locally called "marl"; the portions which are quarried for building-stone consist of a firm but light and porous rock, which forms what would be called a freestone in England, but in Barbados is generally termed "sawstone." This is not an oolite, but consists mainly of coral-sand and shell-débris with some scattered corals, but the quarrymen naturally select the parts where lumps of coral are fewest, and where the rock is of fairly even grain.

Above the 300-feet level the rock is often hard and compact, and is capable of being used for mending the roads, but in other places it is of a loose and rubbly nature, due apparently to the abstraction of material by percolating water.

Both above and below the 300-feet level the harder and softer varieties of stone often alternate one with the other; here and there hard layers occur which form floors across the roadway, and require a heavy blow to break them; some of these layers appear to have been formed by a growth of hard compact nullipore-rock *in situ*, others are simply fine chalky sediment which has been compacted by the infiltration of a calcareous cement. Where the grain is coarser the differences of hardness are doubtless due to the different action which the percolating waters have had at different places and levels. In places where the water has had a free flow it has abstracted material and carried it away in solution, but where the flow has been checked, or it has had to pass through a bed of finer grain, some of the dissolved carbonate of lime seems to have been deposited in the form of a calcareous cement.

In tropical countries notice must be taken of the capillary action set up in the subsoil by the rapid drying of the surface in the sun's heat. Thus, after a shower, the rainwater sinks into the ground, and dissolves a certain amount of limestone, but on those spots where the heat of the sun is concentrated, and especially where the surface of the soil is bare of vegetation, a reverse action must after a time be set up, the sun's heat evaporating the moisture from the surface, and causing capillary currents from below and from the sides of the drying area. The water thus drawn upward from the rock will contain carbonate of lime in solution, which material will be deposited in the interstices of the rock as the water itself is evaporated. We have noticed that the bare surfaces of coral-rock, especially on the higher parts of the island, generally have a very hard crust, which is not an external accretion, but an indurated portion of the rock, and we attribute this to the deposition of carbonate of lime by the process above indicated. In these districts the rock is often appreciably hardened for several feet from the surface, but at a certain distance becomes quite loose, porous, and easily quarried.

At the Crane, in the S.E. of St. Philip's parish, the shore-line consists of cliffs of coral-limestone, which exhibit to a greater extent than elsewhere the differences which we have described as due to the partial solution and redeposition of the limestone. South

of the Crane Hotel the rock becomes very hard in places, and great difficulty was met with in sinking a well through it. Under the cliffs freshwater springs are seen, which discharge large volumes of water with some force. The surface of the cliffs is hard, and is in places coated with the mammillary form of aragonite. A recent cutting on the surface of the cliff has, however, shown that, as described elsewhere, this surface-hardening of the rock does not extend very far inwards.

The mass of the rock generally consists of the broken fragments of corals, nullipores, mollusca, foraminifera, and echinodermata, the relative abundance of the fragments referable to each of these classes being generally in the order stated, although occasionally beds occur which consist chiefly of nullipores or of foraminifera without any recognizable coral-débris.

Where (as is usual) the rock consists mainly of coral-fragments, lumps and broken branches of *Porites* and other corals are scattered through it, and occasionally large blocks of *Heliastræa*, *Siderastræa*, and other massive reef-corals occur in the position of growth, but the number of coral-fragments above 3 inches long is seldom large enough to make up half the mass of the rock. Sir R. Schomburgk has figured some of the large blocks of astræiform corals which are occasionally exposed, and which are sometimes 3 or 4 feet high.

Recognizable shells of Mollusca are not always present; but at the lower levels, and especially where the rock is loose and earthy, they are often abundant and well preserved. At the higher levels the shells have been dissolved, and only casts remain.

The following are notes of exposures seen between Ceres near Bridgetown, and Castle Grant on the central ridge of the island. Ceres is about 70 feet above the sea, and stands on soft marly rock which has a hard crust for 10 or 12 inches below the soil. In this material shells are common, especially univalves of the genera *Natica*, *Bulla*, and *Cerithium*, and bivalves referable to *Arca*, *Lucina*, and *Tellina*. The large *Strombus gigas* is not uncommon, and is found up to levels of at least 400 feet, while casts probably of the same species occur at much higher levels.

Between Ceres and Grasettes the slope which rises from 70 to 100 feet is in many places bare of soil, and the weathered limestone has a dirty grey hue, which gives it a curiously antiquated aspect. Broken and weathered lumps of coral are exposed here and there at the surface, all of them partially calcified, so that the general appearance of the rock and its contents is not unlike the more coralliferous parts of our Carboniferous Limestone. It is, however, by no means hard, having been quarried in several places for building-stone, and then the yellowish-white tint of the freshly-cut rock recalls our Jurassic rather than our Palæozoic limestones.

At Spooner's Hill, above Kew, on the road to Warrens, the rock is loose and soft, having the usual structure, but with an occasional layer of still looser coral-sand. This continues to about the height of 90 feet above the sea, when the road cuts through a much harder rock, the matrix being far more compact, the coral-lumps more

numerous and more completely calcified, so that they do not show the open structure of those in the softer rock; this is probably the outer part of an actual reef. Still higher, at a level of 180 feet, there is a cutting and a quarry exposing rock which is rather harder than that first seen, but not so hard as the intermediate beds. Like that near Ceres, it consists of coral-débris with many broken branches of coral, but few coral masses; the rock is partially consolidated, but is still very porous, and can be worked as a freestone.

At the next hill, near Jackson's estate (300 feet), the rock is much harder again, and contains some thin beds of grey compact limestone. Towards Exchange, near the 400-feet level, there is a cutting in rough coarse-grained rock which resembles that at 186 feet, but shows many open hollows caused by the solution of some of the pieces of coral, apparently the cylindrical branches of *Porites*, while the other corals are altered and partially filled or replaced by calcite.

A similar change takes place about the same level on the road near Endeavour and Locust Hall. At Dayrell's Hill (300 feet) there is a deep cutting in rough rock like that above mentioned, and many of the smaller cylindrical corals are dissolved. In the next cutting (about 400 feet), near Locust Hall, this is still more marked; nearly all this kind of coral has disappeared, and the other corals seem to be casts in calcspar, while the surrounding matrix is harder and more compact than the newer limestones at lower levels.

Similar rock to the last is seen at intervals between 500 and 700 feet, as at Market Hill. In a quarry near Fisher Pond (just above the 700-feet level) the rock exposed is very white and hard, and traversed in all directions by ramifying perforations which are doubtless the spaces left by the solution of the branching corals. This rock had a certain resemblance to some parts of the Chalk Rock of England, in which similar ramifying perforations often occur near the surface and are due apparently to the solution of soft mealy chalk filling the spaces originally occupied by the roots and stems of siliceous sponges. The other corals in the rock at Fisher Pond were casts in calcite of the spaces between the corallites, the coral itself having been dissolved, and in some the spaces left by the solution of the original coral were also partially filled with calcite, and the whole rock has been so calcified and hardened that it is broken up and used for road-metal.

From Fisher Pond and Cole's Cave up to the highest plateau of coral-rock between Castle Grant and Bloomsbury similar hard and altered coral-limestone is found. At some places, at a depth of several feet below the surface, remnants of organic structure were found in the holes, looking more like sponge-fibres than coral structure; but the fibres are probably casts of the small tubular spaces which can be seen in a broken branch of *Porites*, and one specimen shows the cast of a *Vermetus* attached to the fibres.

A small quarry close to Castle Grant exposed a rock which contained a larger number of corals than were seen in any of the places

yet mentioned. The matrix exhibited the usual débris of corals, shells, nullipores, and polyzoa more or less cemented together by lime. Near the surface the rock is very hard, but lower down it is looser and less consolidated, being even friable in some places; this is doubtless due to the continual percolation of water through it, as the quarry is in the side of a large swallow-hole. Large corals standing in the position of growth abound, some of them being 4 or 5 feet broad and 6 or 7 feet high, and where these are somewhat weathered they look like huge decayed honeycombs. They are, as usual, merely casts, but here they certainly make up more than half the mass of the rock. Shells also occur only in the form of casts, species of *Conus*, *Pecten*, *Spondylus*, and *Pectunculus* being recognizable. The height of the ground here is 1050 feet.

We are informed by those who have been concerned in sinking wells in the higher parts of the island that the lower portions of the rock are generally looser and more easily worked than the upper, and that sometimes the lowest portion resembles a mass of loose rubble. As far as we can learn, big blocks or growths of coral are most abundant on the outer slopes of the terraces, and large masses are seldom found in the lower part of deep wells.

Mr. R. C. Piggott, of Castle Grant, informs us that the well at Ellis Castle, adjoining Nicholas-Abbey estate, cuts 150 feet through coral, and he kindly sent us samples of the rock from 130 feet down which were taken out in his presence. One of these was a large lump of a compound coral, identified by Mr. J. W. Gregory (of the British Museum, Natural History) as *Heliastrœa crassilamellata*, Duncan; this is the greatest depth from which we have noted the occurrence of a compound reef-coral.

There are not many places in the island where the base of the coral-rock can be examined; but one of these places is in Cole's Cave, a cavern which opens into a deep gully on Walk's Spring estate, and leads down into an underground watercourse which can be explored for some distance. The limestone here rests directly on the dark clays of the Scotland Series, its basement bed is loose and rubbly, and in a distance of half a mile along the cavern only one lump of coral, about a foot broad, was seen in it.

In the same gully, about three quarters of a mile higher up, is another cave, known as Harrison's Cave, and the coral-rock seen in this is a calcareous sandstone consisting entirely of small débris without any distinguishable corals for a distance of 300 or 400 yards from the mouth. The rock is, in fact, similar to the sandstone formed by the cementation of coral-beach sand, though it was probably accumulated on a submarine sandbank. It rests here on a white Radiolarian earth.

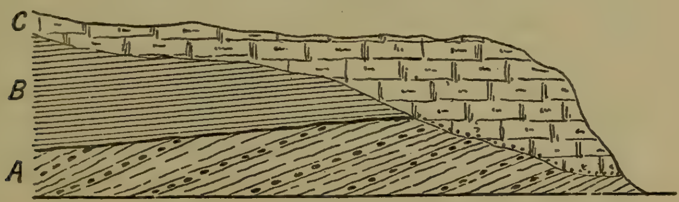
At Edgehill, about five miles north of Bridgetown, and at an elevation of 450 feet, a well was recently sunk for the Water-Supply Company. The coral-rock was found to be 100 feet thick, the first 50 feet being through the usual detrital rock without large corals; then from 50 to 60 feet there were large coral-masses, and below this there were no corals, the material consisting of calcified coral-

sands and muds enclosing a few shells; below it were Scotland rocks, dipping at an angle of 25°.

In a cave recently discovered by the Water-Supply Company between Cole's Cave and Harrison's Cave the solid coral-rock rests on a soft deposit consisting of coral-sand and partly of siliceous Radiolarian earth washed out of the Oceanic Series, and containing many broken and waterworn fragments of corals. This basal deposit is evidently a submarine sandbank formed outside a higher coral-reef; when renewed upheaval brought this sandbank within the limits of coral-growth it became the basis of the next reef.

Caves are not convenient places for geological observations, but there are several localities in the eastern part of the island where the base of a coral-reef is well exposed and easily accessible, and in one of these we find an instructive section showing the complete discordance of the three rock-groups of which Barbados consists. It occurs in a small valley opening into Sheetes Bay on the coast, about half a mile south of Bell Point. To the north of the bay the coral-rock makes up the whole of the cliff, but gradually thins off southward against a bank of Radiolarian earth; this rests on Scotland clays and sandstones out of which the bay has been eroded. In the steep bank on the south-east side of the bay the rocks exhibit the relations shown in fig. 7. The surface of the older rocks is a slope

Fig. 7.—*Section near Sheetes Bay.*




A. Scotland sandstones.
B. Oceanic beds.
C. Coral-rock.

facing eastward, and against this the coral-reef has been built; its base is a conglomerate consisting of ironstone nodules derived from the Scotland clays and cemented by calcareous matter into a hard rock which passes up into a calcareous sandstone from 6 to 8 feet thick. The higher beds consist of rock with corals and coral-débris, and then thin off inland against the slope of the siliceous earths.

At Culpepper Island there is coral-rock resting on a bed of redeposited Radiolarian earth containing small corals and land-shells, and about 8 feet thick; this lies on the Scotland strata, which here occupy the coast-line.

The reefs thus exposed on the coast are of course very recent coral-rock, but the base of an older reef is exposed beneath St. Mark's Church, where the surface is 258 feet above the sea. The coral plateau is here cut back into an escarpment which faces west,

and is from 15 to 20 feet high; it rests on white Radiolarian earth, and its basal bed is a very soft earthy limestone or marl like a friable chalk. This is about 6 feet thick, and appears to be a true coral-mud; an analysis of it is given on p. 224, and its minute structure is described by Mr. Hill (p. 247). This marl passes upwards into a soft marly rock containing many broken pieces of coral, and this in turn gradually changes upwards into a hard limestone. At Codrington College, about 20 yards below the garden, there is only a few inches of coral mud and sand below the coral-rock, and here it rests on a soft yellowish foraminiferal marl belonging to the Oceanic Series.

(d) *The great Escarpment.*—In the north-eastern part of the island the raised reefs are cut off by erosion, and the line of their intersection forms an abrupt escarpment, which is in some places a line of cliffs. This escarpment describes an irregular sigmoid curve round the Scotland District, commencing near St. Mark's Church in St. John's parish, where for a short distance it forms a little cliff facing west; thence it curves round by Sealy Hall, and passes northward to Codrington College, where the base of the coral-rock is about 300 feet above the sea, facing north-east, and running at the foot of a steep slope which terminates upward in a plateau at a level of about 570 feet. Thence both the base and the summit-levels rise steadily to the north-west, while the upper part of the steep slope passes into a vertical cliff.

The finest part of this escarpment lies between St. John's Church (800 feet) and Castle Grant (1079 feet) and includes the range of Hackleston's Cliffs; here there is a vertical face of from 60 to 70 feet of coral-rock, rising from a slope of broken and tumbled masses of the same rock. Most of the cliff-face is covered with small shrubs, ferns, and climbing plants, and much of the slope below is hidden by palms, trees, and underwood, so that when viewed from the railway it looks like a wall of foliage.

At Castle Grant and Little Island the fallen masses of rock are in some places banked to within 20 or 30 feet of the summit, but at other parts there is a vertical face of 50 or 60 feet in depth. The surface of the rock is very rough, being fretted and honeycombed by the action of the rain, and in some places coated with sheets of travertine derived from the solution of its upper portions. Ferns, llianas, and rock-plants of many kinds grow on these cliffs wherever they can find roothold, and add to the picturesqueness of their aspect. Great cracks and clefts occur in many places, and occasionally after heavy rains a huge slice is detached and falls with an avalanche of stones to the bottom.

On the west part of Castle-Grant estate this bold line of cliff ends in a somewhat abrupt manner; the thickness of the coral-rock rapidly diminishes westwards against the slope of the older rocks, which finally emerge from beneath the coral and form a distinct ridge running northwards to Chimborazo at an elevation of between 1000 and 1100 feet. On the west side of this ridge, and separated from it by the valley of a little watercourse, there is a narrow slope of Radiolarian earth, crowned by a miniature escarpment of coral-rock

from 20 to 30 feet high. It is evident that this ridge is part of the original nucleus of the island when it first rose above the sea, and that the plateau of coral-rock which terminates in the low escarpment is part of the earliest encircling coral-reef. Its original boundary-line doubtless lay along the western slope of the ridge, and has been cut back to its present position and scarped by the action of rain and running water. From Chimborazo the ridge curves westward, and though somewhat broken near Caledonia it can be traced to Mount Hillaby, where it rises to over 1100 feet; thence it runs north-westward to Spring estate, where it passes beneath the coral-rock almost at right angles to the course of the latter, in the same way as it started at Castle Grant.

The boundary of the coral-rock conforms roughly to the zigzag course of this ridge, lying always on its southern and western sides, and always presenting an escarpment of greater or less height. Its edge has been cut back irregularly, and it is trenched in some places by deep gullies which are continuations of the watercourses that traverse the western slopes of the Hillaby ridge. Near Hillaby Plantation the layers of coral-rock have a distinct westerly dip or slope away from the Hillaby ridge; the direction varies from a little S. to a little N. of W., and the angle of slope is about 4°. This inclination is probably due in part to original formation on a slope, but it may have been increased by subsequent upheaval.

From near Hillaby to Spring estate the coral-rock lies directly on the Scotland beds, its boundary-line running first N. and then W., while the dominant ridge outside runs also N. and W.N.W. under the coral at Spring. This place is 923 feet above the sea, and here the escarpment begins to present bolder features again, forming a continuous ridge which overlooks the slopes to the W. instead of being itself dominated by a ridge of older rocks. The escarpment thence runs due north for some distance, and preserves its height as far as Farley Hill and Grenade Hall. Thence it trends to the north-east, and both its base and its summit-level steadily descend just as the levels of the corresponding escarpment descend southward from Hackleston's Cliffs. West of Pico Teneriffe it merges into lower terraces which are probably banked against it, but its continuation may be traced in a line of inland cliffs which set in to the northward and run for about a mile to the north-west, terminating near Cave in the parish of St. Lucy.

(e) *Terraces and Patches of Coral-rock below and west of the Escarpment.*—From the account of the escarpment which we have given above it is clear that this feature began to be established at a very early period in the history of the island, and, once started on the higher ground, it would tend to extend itself through the subsequently formed reefs as they were raised above the sea. The original island may have been encircled by reefs, but if so those which covered the north-eastern side have been removed by erosion, and as soon as the streams had cut down to the Scotland rocks the muddy water poured into the sea would prevent the growth of corals, except here and there in favourable situations.

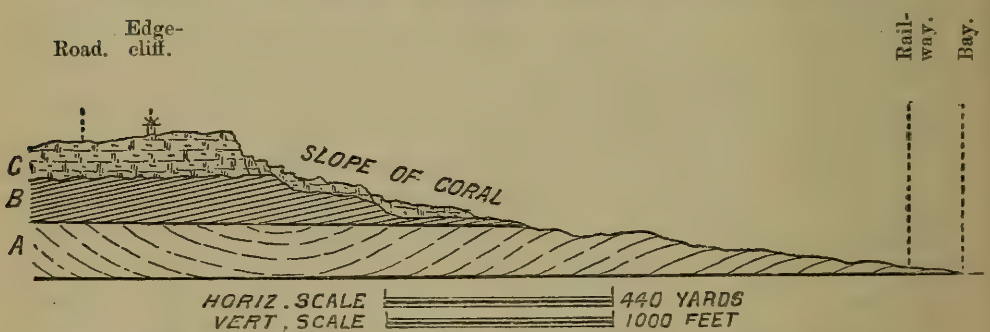
Where, however, the escarpment came near the sea along the

tract from Hackleston's Cliffs to Codrington, it was possible for coral-reefs to form against its foot, and accordingly we find narrow and irregular terraces of coral-rock which may be regarded as continuations of the reefs elsewhere formed between 700 and 800 feet.

Again, it is noticeable that the actual cliffs end below St. John's Church at a level of about 700 feet, and that all the coral-rock plateaux to the southward run in below the line of cliffs from the 700-feet terrace down to that which passes above Sealy Hall at about 300 feet.

Below Hackleston's Cliffs, which rise to 1000 feet above the sea, the slope is covered with coral-rock down to a level of 500 feet near Mount Dacres, according to levels which have been kindly communicated by Mr. E. Easton, C.E., F.G.S. This slope is broken and uneven, owing to the frequent landslips which have occurred by the slipping of the lower reefs over the surface of the Scotland clays. The annexed figure (fig. 8) will serve to illustrate what appears to be

Fig. 8.—*Section from Edgecliff through the cliff to the coast.*




A. Scotland beds. B. Oceanic beds. C. Coral-rock.

the structure of this slope, and we do not think that the thickness of the rock which forms the line of cliffs anywhere exceeds 250 feet.

This view is confirmed by the fact that between St. Joseph's Church and Mount Dacres the base-line of the coral-rock falls from about 800 feet to only 500 feet above the sea, for we believe that this slope is an oblique intersection of the natural slope of the surface against which the reefs were successively formed.

The terraces which occur at a still lower level in the south-eastern part of the island, and which now terminate in the escarpment below St. Mark's Church, doubtless originally extended northwards at least as far as the point where the Oceanic Series is faulted against the Scotland beds. This former extension of the reefs is indicated by several outlying patches of coral-rock not far from the coast-line.

One of these is an isolated limestone rock, about 70 feet high, which overhangs the railway north-east of Codrington. Farther north there is a patch of coral-rock covering about 20 acres, and capping the hill through which the railway passes north-west of Bath Station. Beyond this, however, we do not suppose there were

ever any continuous reefs along the border of the Scotland District, though small patches of reef-rock appear to have been formed in some places, and large blocks of them are now found on the recent beach.

Isolated rocks and outlying patches of coral-limestone occur here and there over the Scotland District at various levels below 500 feet, but mostly between 300 and 400. Some of the rocks that lie at no great distance from the main escarpment may have slipped from thence; others, however, occur in such positions that they could not possibly have been so derived, but must have been formed where they are now found. They generally occupy the tops or lie on one side of small hills, and are sometimes separated from the escarpment by a broad valley. A mass of very hard and white rock as large as a negro's cabin lies on the surface at Vaughan's estate at a level of over 700 feet, and a specimen taken from it proves to be an *Amphistegina*-rock (described in Mr. Hill's 1st appendix to this paper). A large patch of reef-rock occurs on the top of the hill at Bawdens in St. Andrew's parish; this hill is 389 feet high, is a mile to the east of the main escarpment, and separated from it by a wide and deep valley. The highest patch we found is at Lower Turner's Hall, at an elevation of 462 feet, this place being rather more than half a mile south of Bawdens. There are also large blocks of coral below Cherry-Tree Hill at a level of about 450 feet.

At Boscobelle, in the northernmost part of the Scotland District and about 200 feet above the sea, there is a patch of coral-rock occupying about 15 acres; and farther north, between Boscobelle and Pico Teneriffe, there is a platform of the same rock clinging to the seaward side of the Scotland sandstones, with a low escarpment on the west side, reproducing the features of the platform at St. Mark's described on p. 218, except that it has been cut through by the sea at Grant's Bay, south of Pico Teneriffe, and is, therefore, in reality an outlier.

The extreme N.E. part of the island is difficult of access, but we ascertained that it was everywhere covered by coral-rock, except in a few places where the older formations are exposed. The nature of the rock which occurs here below the level of 200 feet is different from the coral-rock of the south. It appears to consist chiefly of broken lumps and blocks of coral-limestone which have been re-cemented by calcareous matter, and the surface is nearly level as if it were a plain of marine denudation. This difference is doubtless connected with the fact that a powerful surf beats on the present coast, excavating huge caverns in the cliffs, which as a rule in this district rise sheer from the sea.

(f) *The Christchurch Ridge.*—This ridge was mentioned on p. 209, but is worthy of a little further description because it appears to consist of an entirely independent set of reefs, and to have an independent basis or foundation.

As limited by the 200-feet contour this tract is about eight miles long, and the portion above 250 feet has a length of about six miles. The ground rises in a series of terraces up to a set of narrow

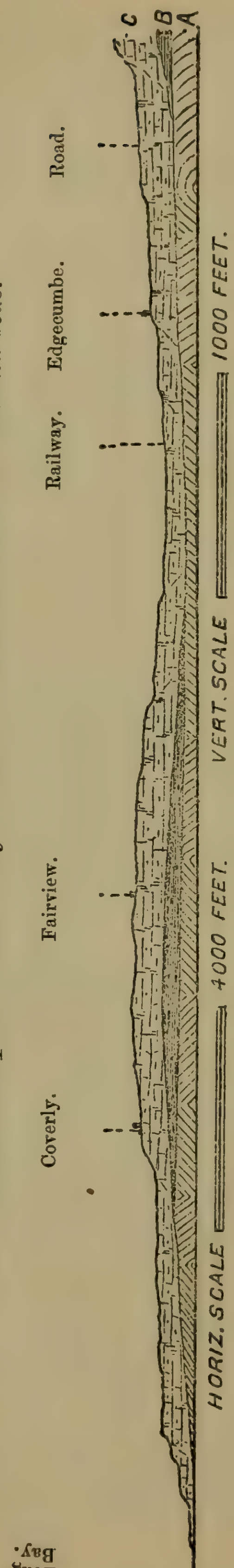



*Fig. 9.—Section through the Christchurch Ridge from Long Bay to the road near Byde Mill, showing the manner in which the Oceanic deposits occur locally between the Coral-rock and the Scotland beds.*

A. Scotland beds. B. Oceanic deposits. C. Coral Limestone.

irregular ridges which have a general east and west direction. In this area there are no deep watercourses or gullies like those which traverse the central part of the island, and all the water falling on it is carried off by subterranean channels.

It is separated from the central part of the island by a low flat plain, which nowhere rises to more than 150 feet above the sea. On the north side of this the ground rises by a series of terraces to about 350 feet, above which there is a steep slope rising in a short distance to 500 feet. The width of this low ground between the two contour-lines of 300 feet is rather less than two miles in the narrowest part, but it broadens gradually both eastward and westward.

From the above description, it is clear that when the sea-level coincided with the contour of 300 feet the Christchurch Ridge formed a separate island, divided from the mainland by a navigable channel with an average width of two miles and a depth of over 25 fathoms. At a still earlier period in the uprise of the area it must have presented the appearance of a small barrier-like reef between three and four miles long by five or six furlongs in width.

At the east end of the ridge and at a level of about 200 feet there is a small exposure of Radiolarian earth, from which it would seem that the coral-rock of the ridge rests on these deposits. On the other hand, the rock which forms the low ground to the north appears to rest on Scotland beds; for in the well at Dodds estate on the farther slope, clay was found directly below the coral.

From these data we have ventured to draw a section across the eastern part of the ridge and to assume that this part of it at any rate is based upon an isolated bank of the Oceanic deposits (see fig. 9).

(g) *Summary of Conclusions.*—From the foregoing account of the raised reefs our conclusions may be summarized as follows:—

1. The thickness of reef-rock formed in a stationary or rising area does not often exceed 200 feet, but may be as much as 260. We must not, however, infer from this that the corals began to grow in 40 fathoms of water, because there is always a certain thickness of coral-mud, sand, or breccia at the base of the reef.

2. Masses of reef-coral have been found in wells down to at least 130 feet, so that we can infer these have grown in 22 fathoms of water, a conclusion which agrees with that obtained by a study of the recent reefs.

3. The detrital rock at the base of the old reefs seems to have been accumulated on a slope outside an older reef. Its thickness varies from 1 foot to 40 or 50, and probably even more in some cases, depending doubtless on the steepness of the underlying slope.

4. The reefs appear to have been formed during successive periods of rest or very slow upheaval, following shorter periods of more rapid upheaval, the movements being similar to those which have affected the west coast of South America.

5. Each movement of upheaval brought up a lower slope within the limit of coral-growth, and sometimes a submarine ridge like that of Christchurch parish, which became an independent site of coral-growth.

6. The rock of the higher terraces is greatly altered by water, some beds being coma cted into a hard and heavy white limestone, others being rendered loose and rubbly by abstraction of carbonate of lime.

(h) *Summary of Varieties of Coral-rock in Barbados.*—From the notes we took in the field, from the information and specimens furnished by Mr. Easton, and finally from Mr. Hill's observations (which will be found in his 1st Appendix to this paper), we think three different kinds or classes of limestone-rocks may be distinguished among the Barbados reefs.

1. *Reef-rock.*—A fairly homogeneous rock consisting of corals and coral-débris compacted together with coral-sand and more or less indurated by infiltration of calcite.

2. *Lagoon and Channel Deposits.*—These are very various both in regard to component materials and coarseness of grain, but they always include a large proportion of other organisms besides corals, such as mollusca, echinodermata, and foraminifera, and sometimes these shells and their broken fragments make up the mass of the rock. Originally these rocks are of a looser texture than reef-rock, but may become compact by infiltration.

3. *Beach-rock.*—This consists of lumps of coral and reef-rock which may have been torn off the outer reefs and cast up on the beach, together with fragments detached from older raised reefs,

embedded in coral-sand and débris. It is sometimes a breccia or boulder-rock, sometimes a rubble-rock, and sometimes a calcareous sand-rock.

## § 4. Analyses of Coral-rocks.

The following are analyses, made by one of us in the Government laboratories of Bridgetown (Barbados) and Georgetown (British Guiana), of seven specimens of coral-rock. The first was a loose unconsolidated rock from an excavation near Bennetts, at a level of about 400 feet. The next three were specimens obtained for us by Mr. Easton from a shaft in Plumtree Gully, east of Endeavour, the surface-level being about 680 feet: Nos. 1 and 2 were from a depth of about 45 feet, and No. 3 from 30 feet down; No. 1 had a brownish tint. The fifth sample was part of that sent by Mr. Piggott from the well at Ellis Castle, taken from a depth of 130 feet from the surface—a rather hard white rock. The sixth was a piece of the hard white limestone with tubular cavities described on p. 215. The seventh was a similar hard limestone taken from near the surface by the road south of Castle Grant.

| | "Marl," Bennetts. | Plumtree Gully. | | | Ellis-Castle well. | Groves hard limestone. | Castle-Grant limestone. |
|---|---|---|---|---|---|---|---|
| | | No. 1. | No. 2. | No. 3. | | | |
| Calcium carbonate | 95·78 | 93·38 | 96·52 | 99·01 | 98·09 | 98·80 | 97·26 |
| Magnesium carbonate | 2·01 | 2·05 | 1·74 | ·56 | 1·25 | ·87 | 2·44 |
| Calcium phosphate | trace | ·05 | trace | ·13 | ·07 | trace | trace |
| Iron peroxide and alumina | 2·27 | ·78 | ·64 | ·35 | ·27 | ·19 | ·17 |
| Silica and clay | ·05 | 3·10 | 1·20 | ·20 | ·48 | ·29 | ·13 |
| Loss on ignition | ...... | ·70 | | | | | |
| | 100·11 | 100·06 | 100·10 | 100·25 | 100·16 | 100·15 | 100·00 |

The following is an analysis of a soft white fine-grained mud or marl from the base of the coral-rock near Codrington:—

| | |
|---|---|
| Calcium carbonate | 97·50 |
| Magnesium carbonate | 1·11 |
| Calcium phosphate | ·21 |
| Calcium oxide | ·41 |
| Iron and alumina | ·05 |
| Silica and clay | ·91 |
| Loss on ignition | ·26 |
| | 100·45 |

The following is an analysis of a curious brownish crystalline concretionary rock obtained by Mr. Easton from a shaft at Cane Garden. If not a pure infiltration-product occupying a cavity, it must be a highly altered coral-rock with much infiltrated material. It was analysed because it somewhat resembled a dolomite, but the amount of magnesia proved to be small:—

| | |
|---|---|
| Calcium carbonate ............ | 84·89 |
| Magnesium carbonate .......... | 1·48 |
| Calcium phosphate ............ | ·04 |
| Iron and alumina ............ | 2·24 |
| Silica and clay ................ | 9·48 |
| Loss on ignition .............. | 2·01 |
| | 100·14 |

### § 5. Palæontology and Consideration of the Age of the Raised Reefs.

We were not able to make a large collection of fossils from the raised reefs, but such as we did obtain have been examined by Messrs. J. W. Gregory and E. A. Smith, of the British Museum (Natural History); the species they have been able to identify afford strong evidence that the whole series of reefs from the lowest to the highest are of recent geological age, and that none of them date back to a time that was anterior to the establishment of the present West-Indian fauna, though the coral fauna includes a few forms which are not yet known to exist in the Caribbean Sea.

The following is a list of the mollusca obtained from the coral rock in the neighbourhood of Ceres and Fairfield, north of Bridgetown, at levels of from 70 to 90 feet above the sea. The specimens were examined and named by Mr. E. A. Smith.

Lamellibranchiata.

*Lucina columbella.*
do. *jamaicensis.*
do. (*Divaricella*) *dentata.*
do. (*Codakia*) *costata.*
*Capsa deflorata.*
*Barbatia*, sp.
*Tellina ephippium.*
do. *decora.*
do. *interrupta*?
do. sp.
do. sp.
*Cardium*, sp.

Gasteropoda.

*Olivella jaspidea.*
*Mitra barbadensis.*
*Cypræa spurca.*
*Pollinices porcellanea.*
*Natica marocana.*
*Obeliscus dolobratus.*
*Columbella mercatoria.*
*Cerithium atratum.*
do. *litteratum.*
do. *eburneum.*
*Murex messorius.*
*Coralliophila*?
*Sistrum nodulosum.*
*Littorina ahena.*
*Leucogonia cingulifera.*
do. var. *angularis*, Reeve.
*Fissurella reticulata.*
*Hipponyx antiquatus.*
*Patella*, sp.
*Bulla striata.*
*Helix*, sp.

Besides these, the large West-Indian *Strombus gigas* and *Cassis flammea* were not uncommon.

From a higher level in Christchurch parish, about 200 feet, *Cypræa spurca*, *Bulla striata*, and *Tellina decora* were obtained for us by Mr. Brocklehurst, jun.

Mr. E. A. Smith favours us with the following remarks on the mollusca :—" From the collection 25 species have been determined, and they are all species found in the West Indies at the present time. The *Barbatia* and the unnamed species of *Tellina* also agree exactly with specimens from the West Indies, but the true specific names are doubtful. Of many of the species there are sufficient specimens to enable a careful comparison with the recent forms to be made, and there is no such variation from these forms as might be expected if the reefs were of considerable age. These lower reefs are clearly of very recent date, certainly Pleistocene, and probably late Pleistocene. The mollusca are such as might be found in a raised beach."

It is interesting to note that Mr. R. J. L. Guppy, F.G.S., in 1866 had observed that the coral-rock of Barbados contained a large number of recent species of mollusca, and that no extinct species had been recorded from it*.

Mr. J. W. Gregory, F.G.S., has examined the small collection of corals which one of us brought back to England, and we have to thank him for the amount of time and trouble which he has expended on the work. He reported that he found it difficult to compare the broken fossil corals, many of which were only casts in infiltrated calcite, with the perfect recent specimens in the British Museum. To meet this difficulty a special collection of recent corals from the Barbadian reefs was obtained and sent over by Mr. G. F. Franks, M.A., F.G.S., to whom we are much indebted both for this and for valuable aid in collecting fossils from the rocks of Barbados. The corals are not yet fully worked out, but Mr. Gregory has been able to identify the following species; of the localities mentioned Ceres is about 70 feet above the sea, Ellis Castle about 500 feet, Groves is about 700 feet, and Castle Grant 1050 feet.

i. Identical with species now living in the Caribbean Sea.

*Stephanocœlia intersepta*, Esper. Ceres.
*Siderastræa galaxea*, El. & Sol. Ceres, Castle Grant.
*Madrepora cervicornis*, Lam. Ceres.
*Diploria cerebriformis*, Lam. Castle Grant.
*Orbicella cavernosa*, Esper. Ceres.

ii. Uncertain or new species.

*Colpophyllia* near to *breviserialis*. Castle Grant.
*Hydriophora*, sp.

iii. Identical with species described by Prof. Duncan.

*Heliastræa barbadensis*, Dunc. Groves and Castle Grant.
*Cyphastræa costata*, Dunc. Ceres.
*Solenastræa Verhelti*, Ed. & H. D. *fide* Dunc. Castle Grant.
*Heliastræa crassilamellata*, Dunc. Lion Castle and Castle Grant.

* Quart. Journ. Geol. Soc. vol. xxii. p. 578.

Of the *Hydriophora*, Mr. Gregory remarks that he is not aware of the genus having been previously recorded from the West Indies, and that the species is almost certainly new. With this exception he says the assemblage agrees closely with the recent West-Indian fauna, and he sees no evidence of any Pacific intermixture or influence, adding, "the genera are all Atlantic forms, and there is an entire absence of typical Panama genera such as *Montipora*, *Pavonia*, and *Pocillopora* (the last of which is known, but very rare, in West-Indian seas)."

It appears, therefore, that of those which can be identified, more than half are recent species, and the rest are forms which are at present only known from Prof. Duncan's descriptions of fossil West-Indian corals *. It is possible, however, that these fossil forms are not so different from recent species as Prof. Duncan imagined, and that the apparent differences are largely due to their occurrence in the state of casts.

It will be noticed that two of the species which still live in West-Indian seas occur in the highest part of the island, and that one of Prof. Duncan's fossil forms occurs in the lowest and most recent reefs. From this it would appear that the whole succession of reefs is of comparatively recent geological date—a conclusion which agrees with the inferences deducible from the stratigraphical evidence.

Prof. Duncan, however, regarded as Miocene all the deposits containing the corals which he described, and we are consequently compelled to examine the reasons he had for this belief. These do not appear to be very strong, and indeed the following extracts will show that his conclusion is founded solely on the general resemblance of the corals to species which occur in the European Miocene, and that there are facts which tend to directly controvert his view.

He admits (*op. cit.* p. 452) "that the Testacea sent from Antigua with the corals have been stated to belong to the present age." He was aware also that late Tertiary shells and corals occurred both in Jamaica and San Domingo, but he thinks this is not antagonistic to his view, and says: "So with regard to Antigua, Barbuda, and Barbados it is not correct to give the whole islands a Pliocene or post-Pliocene age, because recent and subfossil shells are found in them." In all this, however, he overlooks the fact that the shells in question have been obtained from all three of the islands mentioned in *actual association* with the corals which he would class as Miocene fossils. Now it can hardly be correct to attribute to deposits a Miocene age when all the mollusca found in them are recent species.

On p. 453 (*op. cit.*) he admits that "the range, in strata, of the genera of corals is often so great, and the species of remote formations are so frequently closely allied, that the Zoantharia form better guides for estimating the external physical circumstances of the regions in which they existed, than for determining the age of strata."

* Quart. Journ. Geol. Soc. vol. xix. (1863) p. 406.

After this explicit statement it seems strange that he should still venture to rely upon the corals alone for determining the age of the West-Indian faunas. He points, however, to the occurrence of some of the corals in other islands, and in formations which have on other grounds been regarded as Miocene. It must, on the other hand, be remembered that our knowledge of the geology of these islands is still very incomplete, and that though there is a sequence of Tertiary deposits both in Trinidad and Jamaica, the relations of the several rock-groups to one another are by no means certain. From facts which have come to our own knowledge we are strongly inclined to believe that the true stratigraphical sequence of the Tertiaries in both these islands has yet to be made out.

Again, on p. 454 (*op. cit.*) he admits that in Antigua itself the determination of the exact age of the trap, the conglomerate, the chert, and the marl is open to doubt, but says "that these three last strata should be of the same age as the coral-reefs in the surrounding sea is impossible, inasmuch as the silicified corals have a greater resemblance to European fossil forms, and to Pacific and East-Indian recent forms, than to those of the present Caribbean Sea." This argument can hardly be regarded as logical, for the silicified corals occur in the chert, not in the marl, and the chert and the marl may well be of different ages (see *infra*, p. 231), as indeed we believe they are; in fact his own lists show that out of 23 species found in the two formations only one is common to both. This species he identifies with *Alveopora dædalea*, which occurs also in the Pliocene "White Limestone" of Jamaica, and still lives in the Pacific Ocean. There is, therefore, absolutely no evidence for the Miocene age of the Antiguan "marl," though according to Prof. Duncan its coral fauna has certain affinities with that now existing in the Pacific.

He observes that "the absence of simple corals from the collection from Antigua is somewhat remarkable, especially when their prevalence in San Domingo and Jamaica is considered." In this the Antiguan deposits agree with those of Barbados, and the fact is a proof that we are dealing with raised reefs only. "Equally remarkable is the presence of no less than nine species of *Astræa* [seven in the marl], some of them second to none in size and development" (*op. cit.* p. 445). Prof. Duncan thinks that the large blocks of these *Astræa*, together with species of *Alveopora* and a large *Rhodoræa*, indicate a reef with Pacific rather than West-Indian peculiarities. In the light of more recent information, however, it is doubtful whether the Pacific affinities of the fossil fauna are so strong as Prof. Duncan at that time supposed.

With regard to Barbados, the sole evidence on which a Miocene date is claimed for the coral-rock is the occurrence of a species of *Astræa* to which the name *barbadensis* was then given, and which is described as being more closely allied to the recent *A. annularis* of the Pacific than to the *A. stellulata* of the West Indies. A cast of the same species was obtained from the "marl" of Antigua, but it is obvious, from the preceding remarks, that this in no way

strengthens the supposition that the Barbadian rock is of Miocene age. Prof. Duncan mentions two other corals from Barbados, but they were not specifically recognizable, and it was uncertain whether they had been obtained from the raised reefs. The occurrence of *Astræa* (now called *Heliastræa*) *barbadensis* was then the sole link between the reefs of Barbados and Antigua, but the connexion is now strengthened by Mr. Gregory's discovery of *Heliastræa crassilamellata* in the higher reefs of Barbados.

In respect to Barbuda, the only coral yet obtained from that island is the species described by Prof. Duncan under the name of *Cyphastræa costata*. This has now been found in the lower reefs of Barbados, and will doubtless be discovered in Antigua and Guadalupe when those islands are more thoroughly searched. Prof. Duncan also records it from San Domingo and Jamaica, so that it constitutes another link in the chain of evidence that the collections examined by Prof. Duncan included a mixture of Pleistocene, Pliocene, and possibly some Miocene species. A species of *Cyphastræa*, *C. oblata*, still lives in the Caribbean Sea, and others occur in the Pacific; but Prof. Duncan considers that the fossil form differs from all of them.

Barbuda being a small low island, and the shells in the coral-rock being all of recent West-Indian species (see p. 231), there is really no ground for regarding as Miocene the bed from which the *Cyphastræa* came. The fossil indeed is expressly stated to have been obtained "from the hard superficial limestone."

Finally, with regard to the alleged resemblance of the fossil corals with recent Pacific species, such affinities (admitting that they exist) would be completely accounted for if there had been free communication between the Pacific Ocean and the Caribbean Sea up to a late Pleistocene date, and, as we shall show, there is a high probability of such communication having existed.

Prof. Duncan truly observes that the gradual upheaval of the former coral-reefs and banks must have caused a vast alteration in the physical geography of the West-Indian seas, and that "the area of elevation was a vast region;" yet he still infers that this upheaval terminated the Miocene age in the Caribbean region, and it does not seem to have occurred to him that the Pacific affinities and the general Miocene aspect of the coral faunas which are preserved in the later Caribbean Tertiaries might be due to the peculiarity of the geographical conditions which preceded this immense physical change.

## § 6. Comparison of the Raised Reefs of Barbados with similar Formations in other West-Indian Islands.

It is now well known that raised reefs and coral-limestones, similar to those of Barbados, occur in many of the Antilles, but our information regarding the structure and fossil contents of these coral-rocks is still meagre. We have gathered such information as we could regarding them, the very deficiencies of which will show

how large and interesting a field of enquiry still remains in this region.

(a) *Guadalupe.*—This island is divided into two dissimilar portions by deep inlets; the western peninsula is entirely volcanic, but the eastern, which goes by the name of Grand' Terre, is entirely composed of raised coral-reefs and their associated calcareous deposits. It is described as presenting "an undulating elevated alluvial soil, above which rise a number of small steep round hills, or *mamelons*, to a height of perhaps not more than 1300 feet. These hills are composed of fossiliferous limestone, full of shells and corals of the same species as are still found alive in the neighbouring waters.* ". A few species of corals from this rock have been described by MM. Duchassaing and Michelotti, but so far as we can learn no complete account of the rock or its fossils has ever been published. It is worthy of notice that the elevation of its highest ridges above the sea (less than 1300 feet) tallies very closely with that of Barbados (1100 feet).

(b) *Antigua.*—This island, which lies to the north of Guadalupe, exhibits a very similar structure. Our knowledge of its geology has not been enlarged since the publication of Dr. Nugent's Memoir in 1821 †. The island contains 108 square miles, and its western part consists mainly of volcanic rocks; but the whole of the north-east portion, which is about half the superficial area of the island, consists of coral-rock, the "marl" or "calcareous formation" of Dr. Nugent. He describes its general aspect as a broken undulating district, rising into round-backed hills and knolls, the highest of which are between 300 and 400 feet above the sea.

Of the rock itself he says:—"Throughout the greater part of its extent this calcareous formation consists of a closely impacted marl, readily broken down by the hoe or other means, and then assuming a friable and pulverulent appearance, either of a white or light yellowish colour, containing no other foreign admixture than that of certain shells and corallines, and perhaps decayed vegetable substances. Through this marl run in a great many places layers and irregular masses, of various sizes, of a tolerably compact limestone, which generally breaks into rounded fragments, containing a considerable variety of fossil shells, nodules of calcareous spar, and small patches and druses of cellular and crystallized quartz, chalcedony, and agate." In other places there are included layers of siliceous gritstone, of smooth-grained calcareous sandstone (used for a building-stone), and occasionally of puddingstone or breccia, with fragments derived from the older rocks of the island. "The calcareous formation is replete with a variety of fossil shells and corallines, both in a calcareous and a siliceous state; but whether they are of different species from those now inhabiting the surrounding sea future observation must point out."

In some portions of the rock the fossils are preserved in agate

* Bates in Stanford's 'Compendium of Geography,' 2nd ed. p. 179.

† Trans. Geol. Soc. 1st ser. vol. v. p. 459, with map and sections.

and chalcedony of various colours; and he expressly states that these are different from the siliceous fossils of the "Chert," a hard splintery rock which he describes as "subordinate to the lowest beds of the calcareous formation." He regards this Chert as part of the Marl formation, though he was at first inclined to consider it older. The facts he mentions are indeed quite consistent with the view that it is older, and that it is enveloped by the coral-rock which thus sometimes seems to lie below it. Prof. Duncan takes the same view, for he says that the Chert occurs in masses of limited extent, and has evidently suffered from various wearing causes during the deposition of the Marl. This conclusion is confirmed by the difference in the fossils of the two formations; the mollusca are not the same, and out of twelve species of corals found in the Chert only one occurs also in the Marl.

Reference to the Admiralty chart shows that Antigua stands on the southern edge of a large submarine plateau, and that soundings of less than 20 fathoms extend continuously over a large area to the north and north-west of the island. On this plateau there are numerous coral-growths some of which are covered by one to five fathoms of water, others are marked "coral heads nearly dry," and others are reefs dry at low water.

Off the north coast of the island, for a distance of nine miles, there is a series of such reefs and shoals divided by narrow channels which open into a wide inner channel, where the depth varies from 6 to 8 fathoms. The conditions here are very favourable for the growth of coral, for no rivers debouch on the shore, and there can be little doubt that the reefs are still growing. Eventually they may form a true barrier-reef on a small scale, separated from the shore by a navigable channel; for this is evidently kept open by the currents running through it, and, though the nature of the bottom is not indicated on the chart, the soundings show that it has a smooth and even floor, which doubtless consists of coral-sand.

(c) *Barbuda* is a low bare island, lying about 35 miles north of Antigua, and of rather smaller dimensions. It is thus described by Dr. Nugent in a letter to Mr. Greenough in 1818 *:—"This island is perfectly flat, and scarcely elevated above the level of the sea, except in one corner, where it rises to the height of 117 feet. It is entirely composed of limestone, which for the most part is perfectly naked and bare, whilst in no place is the depth of soil greater than two or three snakes (*sic*), and this is lodged generally in the clefts or cup-like cavities worn in the surface."

"I send herewith specimens of a compact white limestone [from the neighbourhood of the castle and settlement]. It abounds with fossil shells, belonging principally to a small species of *Bulla*. Other shells also occur in it less abundantly, of which the following genera have been ascertained,—*Arca*, *Cardium*, *Oliva*, *Turritella*, *Voluta*, *Strombus*; also two species of Madrepore." He observes

* Trans. Geol. Soc. 1st ser. vol. v. p 474.

that these fossils "appear to be in no wise different from the shells inhabiting the surrounding waters," but that the limestone is not exactly like any of that in Antigua.

As he describes the limestone as white and compact, it has probably been altered and indurated by the percolation of water, like so much of that in Barbados. The *Bulla* is doubtless *Bulla striata*, so common in the lower terraces of Barbados and one of the corals, described by Prof. Duncan by the name of *Cyphastræa costata*, has now been identified by Mr. J. W. Gregory among the corals we brought from Barbados.

In a note to his "Geology of Antigua" (*op. cit.* p. 463) Dr. Nugent states that during a visit to Spanish Point, the south-eastern point of Barbuda, he found a yellow marl containing marine shells, *Pyrula*, *Trochus*, *Cypræa*, and *Buccinum*, together with the same *Bulimus* and *Helix* as those which occur in the Marl formation of Antigua and another land-shell which he had not met with in a living state.

Mr. R. J. L. Guppy * refers to the island in the following terms:—"Barbuda contains a formation resembling the coral-limestone of Barbados. It consists of a white calcareous deposit full of shells, all of which are, as far as I have examined, of existing species." He adds, "the existence of a Miocene formation in that island seems nevertheless to be indicated by the corals described by Dr. Duncan;" but we have already discussed this case (p. 229).

(d) *Anegada*, the northernmost island of the Virgin group, is interesting chiefly because it is an example of the appearance presented by a coral island which has just been raised a little above the level of the sea. It was carefully surveyed by Sir R. Schomburgk in 1831 †, who describes it as a long low island, no part of which is more than 60 feet above the sea. It consists entirely of coral-rock and coral-sand, the surface rising in some places into mounds and in others dipping below sea-level into irregular depressions, which are filled with salt water and form large ponds or lagoons. "The bottoms of all these ponds are shelfy and uneven, with heads of coral-rocks often rising in them above the surface of the water. . . . The southern side of the island is a continued mass of shelves loosely covered with vegetable earth more or less mixed with sand . . . . and the shelves are intersected with openings, sometimes narrow, sometimes of considerable width and depth. . . . Fresh water is found in great abundance on almost every part of the island, frequently even in the immediate vicinity of the sea and surrounded by salt ponds. On the north side, near Loblolly Bay, are a range of shelf-holes, called the Wells, which are filled with fresh water." He found the depth of these holes was from 12 to as much as 36 feet; their width at the surface being from 10 to 25 feet, and the hole narrowing downwards in the form of a funnel.

* Quart. Journ. Geol. Soc. vol. xxii. (1866) p. 578.
† See Journ. Roy. Geogr. Soc. vol. ii. (1832) p. 152.

From the preceding description it is clear that the rain which annually falls on the island is sufficient to saturate the rock of which it is composed, and that deep swallow-holes are in the process of formation. One can readily understand that if further elevation took place, a subterranean drainage would at once be established, the water would be drained off from the swallow-holes, and some of these would become choked with earth and rainwash, like many of those in Barbados.

Another interesting feature is the existence of an outer line of reefs that completely encircle the island, and are separated from it by a strip of shallow water of varying width. On the north side this reef comes very near the island, but on the south side it is generally two or three miles distant from it, and is in fact a kind of barrier-reef, with anchorage-ground inside for small vessels in $2\frac{1}{2}$ fathoms of water.

The existence of this encircling reef is a demonstration that subsidence is not a necessary factor in the formation of such a reef, which only differs from a true barrier-reef in the depth of the inside channel, a factor which is quite as likely to depend on the original conformation of the bottom as on subsidence. Moreover, we are not left without evidence of the extremely recent date of the final elevation which produced the low shelves that form the southern beach of the island, for Schomburgk says that "on landing the beach is found everywhere coated with a grey, siliceous, and calcareous substance (the predominant ingredients in which are clay, fragments of limestone, and vegetable fibres) which seems to be deposited by the waters; and as the tide retires, hardens, and assists slowly in increasing the island . . . . There can be little doubt that, excepting on the extreme weather face, it once covered the whole island: the impression of feet and birds' claws being distinctly visible in many places now overgrown with underwood and grass; the first being believed to have been left by the Indians on their occasional visits already noticed, the others being recognized as those of birds which still frequent the island."

As a whole, Anegada is interesting as exhibiting an early stage in the development of a raised coral-island. The coral-rock of which it is composed must be based on some older formation, and its aspect is so different from that of the neighbouring Virgin Islands, which are steep-sided masses of volcanic rock, that its basis is more likely to be a fragment of some Tertiary formation, with or without a covering of upheaved oceanic deposits similar to those of Barbados.

(e) *San Domingo.*—The raised reefs of San Domingo were described by Prof. Gabb *, under the name of the "Coast Limestone;" and this limestone is coloured separately on his map. It occupies considerable areas on the southern and south-eastern coasts, the tract east of Santo Domingo city being about 80 miles long by 10 to 20 miles

* Trans. Amer. Phil. Soc. 1881, n. s. vol. xv. p. 103, with map and sections; surveyed in 1872.

broad. Parts of this, and especially the south-east corner, "exhibit proofs of irregularity in the process of upheaval in a series of well-marked terraces," which he compares with the terraces of Barbados as described by Schomburgk.

This tract appears to have been formed as a barrier-reef in front of the ancient coast, which is defined by a parallel tract of gravelly country at the foot of the hill range and at a distance of about 20 miles from the modern coast-line. The coral ridge rises to at least 150 feet above the sea, and where narrowest is backed by an equal width of broad low-lying savannas; but at the S.E. end it rises in a series of terraces to the flanks of the hills.

Prof. Gabb describes its lithological characters as follows:—"The rock is evidently the bottom of a coral sea. It contains a few corals, almost always of the massive forms, though these are not generally disseminated, but occur rather in spots on the sites perhaps of pieces of ancient reef. Occasionally in these collections a branching species may be found, but the small solitary forms are almost unknown. Again, a mass of madrepore is sometimes seen embedded in the matrix and isolated from all companions. But the great bulk of the rock is a very soft, light, cream-coloured, chalky material, the comminuted débris of coral, &c., such as is forming at the present day among the coral-reefs of the Bahamas and the Bermudas. The local name of this material in Santo Domingo is *caliche*. It has the peculiarity that it hardens on exposure to the atmosphere, though not always to the same extent. Usually, in natural exposure, this hardening takes place to a depth of from two to four feet, though often the crust is not more than a foot thick. The indurated portion is sufficiently solid for building purposes, though it is almost invariably penetrated in all directions by small cavities, caused partly by the decay of the enclosed fossils."

He further remarks that "the whole deposit seems to be homogeneous; no signs of stratification or differences in degrees of hardness being perceptible below the above-mentioned crust. There can be no question but that the greater part is derived from the corals, and the few shells which lived, died, and decayed on the spot." In some places there are "abundance of shells of *Ostræa*, *Lucina*, and of *Veneridæ*, and casts of *Strombus* are nowhere rare." Although it covers such a large area, it does not appear to be anywhere very thick. At Santo Domingo city the bluff is about 40 feet high, but its base is not seen; the wells in the city average 50 feet deep, and reach to the level of the sea. Farther back, where the ground rises, the wells reach the same level; two miles N.E. of the city a well is 158 feet deep, and another not far off is 170 feet. The surface of the limestone is everywhere covered by a peculiar red soil, which is clearly the result of its decomposition.

As regards its age, he remarks that it lies unconformably on the late Miocene, and must be either Pliocene or newer.

(f) *Jamaica.*—Raised masses of coral-rock appear to fringe a large part of the coast of Jamaica, but little information exists with regard to the occurrence of coral-limestone at higher elevations in-

land. From the "Reports on the Geology of Jamaica" (Mem. Geol. Survey, 1869) it would appear that the only rocks recognized as ancient coral-reefs by the Surveyors were those which border the present coast at levels below 100 feet. Even these are not termed "Raised coral-reefs," but are described under the name of "Coast Limestone." Of this the following account is given by Mr. Wall (*op. cit.* p. 109):—"Many of the projecting headlands consist of a calcareous deposit enclosing large masses of coral, usually unaltered, and also numerous shells precisely similar to those inhabiting the adjacent sea, but decolourized; several successive beds occur more or less fossilized in the lower part of the series. From such considerations it results that the coast-limestone is a comparatively recent formation, and must be referred to the post-Pliocene era, since the organic remains exhibit no variation from the species of the now existing fauna. This group also exhibits the final efforts of those mechanical forces that elevated the various formations of Jamaica to the actual positions in which they are now seen." He states that "the Coast Limestone rarely extends far inland, and is never seen at great elevations."

The structure of the rock, as exhibited in St. Elizabeth's parish, is thus described by Mr. C. B. Brown (*op. cit.* p. 209):—"This formation is composed in places of vast masses of large compound corals embedded in and cemented firmly by carbonate of lime and marl, while in others it is composed of a similar aggregation of coral-masses in a loose, soft, yellowish marl, in places here and there more consolidated . . . . Besides the numerous fossil corals in this old reef there are many univalve and bivalve shells, together with Echini."

Few, we think, can read and compare the descriptions of the "Coast Limestones" in Jamaica and San Domingo without being convinced that they occupy similar relative positions, and that they are in all probability similar and contemporaneous deposits. But Prof. Gabb, while adopting the name of "Coast Limestone" for the raised reefs of San Domingo, has failed to perceive their close analogy with those of Jamaica. He correlates the Domingan "Coast Limestone" with the formation known as the "White Limestone" in Jamaica, solely on the ground that the "White Limestone" contains corals, and that it decomposes into a red soil.

The "White Limestone" of Jamaica is described as a massive and bedded formation 2000 feet thick, and occupying some six-sevenths of the total area of the island. The Surveyors were at first inclined to class it as Miocene, but subsequently referred it to the Pliocene.

At the same time it is possible that this "White Limestone" includes parts of more than one formation, for the descriptions given of it show that while the lower part (500 feet) has fairly constant lithological characters, the upper part exhibits very varied structure, being often shelly and coralliferous, and generally almost horizontal, while the lower beds in the same district are tilted and disturbed. Moreover, the Surveyors state that the "Coast Lime-

stone" often rests conformably on and passes down into the uppermost member of the White-Limestone series (*e.g.* in the parishes of Metcalfe and St. Mary). It is not unlikely, therefore, that the so-called "White Limestone" includes high-level reef limestones of post-Pliocene date which have a greater general resemblance to some portions of the older limestone series than to the more recent coral-rock of the coast. It is, indeed, remarked of the "Coast Limestone" in the parish of Westmoreland that it here much resembles the "White Limestone" in outward appearance. Both in Cuba and Barbados the difference between the rock of the lower and higher levels is very great, and if there were not a continuous series of platforms illustrating the process of alteration, the idea of their belonging to different formations might have been entertained.

It is a curious coincidence that after the above was written we found the following passage in Mr. W. O. Crosby's paper on the "Elevated Reefs of Cuba":—"On the island of Jamaica precisely similar reefs have been observed at an elevation of 3000 feet; and Mr. Sawkins, in his Report on the geology of that island, says that the reef limestone has a maximum thickness of not less than 2000 feet, and that the oldest of it was formed after the close of the Tertiary period."

It does not appear that Mr. Crosby is personally acquainted with Jamaica, and he is certainly not justified in drawing such inferences from Mr. Sawkins's Report. The rock referred to is evidently the "White Limestone," but Mr. Sawkins never calls it "Reef Limestone," nor does he make any such statement as to its age.

As we have already suggested, it is not unlikely that some of the so-called White Limestone is raised-reef rock, but it does not follow that the whole of it is. For further evidence on this point see Mr. Hill's 2nd Appendix to this paper.

(g) *Cuba.*—The raised reefs of this island are apparently on a larger scale than in any of the other islands, and are even more conspicuous than in Barbados. The first to recognize the true character of the raised reefs of Cuba appears to have been Dr. Daubeny, for we find the following notice of them in his work on Volcanos (second edition, p. 468):—"Humboldt speaks of calcareous rocks found near Matanzas which belong to the Jura formation, but during the cursory visit which I paid to that locality in 1838 I only observed an extensive coralline limestone of recent date upheaved from the sea. It contains large caverns, and is filled with a profusion of very beautiful corals, as well as of shells belonging to species now existing. It forms a kind of belt along the northern coast, not only between Havana and Matanzas, but I believe for a much greater distance, and is probably one of the most extensive coral-beaches to be found in any part of the world."

The best and most recent account of the Cuban reefs is by Mr. W. O. Crosby, from whose description we quote the following paragraphs*:—

* Proc. of Boston Nat. Hist. Soc. vol. xxii. (1882) p. 124.

"One of the most striking features presented by the island of Cuba, when viewed from the sea or from salient portions of the coast, are the broad, level, and vertical-walled terraces or shelves of rock which rest against the jagged mountains of the interior, and form the shore around almost the entire island. I have observed these terraces lying at various levels from twenty up to nearly two thousand feet above the sea."

The first terrace he describes as having a uniform altitude of about 30 feet for hundreds of miles, unbroken save where rivers have cut through it, and varying in width from a few rods to a mile or more. The rock is largely made up of recent-looking corals, but on the landward side natural sections show some interstratified layers of sand and gravel.

"The second reef rises steeply, often perpendicularly, from the inner edge of the first; and along the north coast, where most of my observations were made, its altitude varies from 200 to 250 feet, the variation being due to unequal erosion. . . Being much older than the lower reef, the limestone is distinctly more crystalline, and the corals and shells are in great part obliterated, so that much of the rock appears quite destitute of organic remains."

"The altitude of the third reef is about 500 feet. It differs from the second very much as that differs from the first, having suffered greater erosion and being still more solid and crystalline."

Remnants of a fourth reef occur at intervals, and its elevation appears to be about 800 feet. "These ancient coral-reefs extend, with slight interruptions, around the entire coast of Cuba." He states that they are better preserved in the western than in the eastern part of the island.

Mr. Crosby then describes the mountain called El Yunque, situated to the west of Baracoa, and rising to a height of 1800 feet. Up to a height of 800 feet the mountain consists of ancient eruptive rocks and slates, but from that height to the summit there is crystalline limestone, which he considers to be part of a still older reef, and to which he attributes a thickness of 1000 feet.

If, however, the El Yunque limestone is really reef-rock, it is probably in the form of a series of reefs covering and investing an interior dome of older rock, and not in that of a solid mass 1000 feet thick in the centre. When, therefore, Mr. Crosby argues that reefs of such great thickness could not have been formed during elevation because the corals could not grow in water 1000 feet deep, he is basing an argument on an unproved assumption. He also states that the third reef "includes not less than 400 feet in vertical thickness of coral rock," but he omits to say how he formed the estimate; no measurement except that of a well or boring, or a vertical cliff, would be free from doubt.

Moreover, it is highly probable that the lower part of the reefs, as in Barbados, consists of débris-rock, and does not contain coral-masses in the position of growth. Prof. Alex. Agassiz has suggested that much of the Cuban reef-limestone may be similar to the Yucatan and Florida limestones, which consist of the shells and

tests of various marine organisms, only the upper part being truly coral-rock *.

Prof. Agassiz found raised reefs also on the southern coast, especially on the hills surrounding Havana and extending to Matanzas. "These hills," he says, "attain a height of over 1200 feet, and are entirely composed of species of corals identical with those now found on the living reefs" (*op. cit.* p. 71).

I entirely agree with him in thinking that the raised reefs of Cuba were formed during periods of rest, each of which was succeeded by a period of elevation; but I cannot agree with his view that Florida was originally joined to the raised reefs "which formed before the Tertiary the two extremities of Cuba" (*op. cit.* p. 75).

### § 7. Physical Geography of the Caribbean Region during the Formation of the Reefs.

From the foregoing descriptions of the raised coral-reefs of the West Indies it is clear that many of the islands have been raised through a considerable vertical height in a comparatively recent period, and it also seems safe to infer that the elevation of these islands has been due to a general regional uplift, and not to a series of special and local upheavals. If the raised reefs only occurred on small islands like Barbados and Antigua, which exhibit signs of special local upheaval, we could not have been sure that there had been any general regional elevation since Pliocene times, though it would be difficult to account for the uplift of deep-seated oceanic deposits without supposing a great and extensive elevation. But as coral-rock is found at high elevations in Cuba, and probably also in Jamaica, we are entitled to assume that the upheaval of the other islands was part of a regional movement. The proved extent of this movement in the eastern part of the region is 1300 feet, and in Cuba about 1800 feet.

The larger islands were in existence when the highest reefs began to form around them, but the Windward Islands must have been few and small. We may assume that Barbados and the eastern part of Guadalupe (Basse Terre) made their appearance about the same time, and that the little islands of Barbuda and Anegada were among the last to rise above the waves, their appearance in fact being contemporaneous with the formation of those Barbadian terraces which lie below the 100-feet contour.

The distance between Barbados in the east and Havana in the west of the region is about 1800 miles, and, as the height to which the reefs have been lifted in Cuba is rather greater than that of the highest reefs in the Windward Islands, we may assume that the upheaved area extended still farther to the west. Now, Havana is only 300 miles, and the west cape of Cuba only 140 miles, from Yucatan, which is known to be a raised plateau of recent marine limestone, and was clearly, therefore, within the area of elevation.

* See footnote, p. 110, in Bull. Harvard Mus. vol. xiv. (1888), "Three Cruises of the 'Blake.'"

In a paper read at the Leeds (1890) meeting of the British Association, Dr. J. Crawford describes the eastern part of Nicaragua as a zone 80 to 100 miles wide, consisting of lagoons, swamps, and deltas with a "raised bed of sand." He also states that raised Pliocene beds occur on both sides of the main ridge.

Farther south, in Panama, there are also indications of recent upheaval; thus the isle of Manzanilla, on which Aspinwall stands, is a raised coral-reef, and Mr. J. A. Lloyd states that there is coral-rock on the northern or Atlantic side of the isthmus, and an indurated clay on the south side of the main ridge *.

We are informed by Mr. Edw. Easton, C.E., that a civil engineer who had constructed a railway in Colombia told him that some of the cuttings up to a level of 500 feet were through coral-rock of recent aspect.

We deem ourselves, therefore, entitled to assume that the whole Colombian and Central-American area participated in the upheaval of the Caribbean region. We may perhaps go further, saying that there are grounds for regarding the line of the Antilles as an extension or offshoot of the Andes, and for believing that there has been a contemporaneous elevation of the whole Andean range from Cape Horn to Guatemala, and of the whole Antillean chain from Cuba to Barbados.

We think it has been shown that the raised reefs of the Antilles cannot be referred to the Miocene period, and that the oldest of them does not date farther back than an epoch which would be termed early Pleistocene in European chronology, while the movement may have been in progress down to the time of human occupation. We look upon the raised coral-reefs of the West Indies as phenomena that are analogous to and contemporaneous with the well-known raised beaches of western South America.

Let us now go back in thought to the time when this great upheaval commenced, and attempt some restoration of the geographical conditions of the Caribbean region on the assumption that it has risen through nearly 2000 feet in the Pleistocene epoch; or, in other words, that the Caribbean and Panamic coasts were, in early Pleistocene time, nearly 2000 feet lower than they are now. In the first place all the larger West-Indian islands were much smaller, while the Bahamas and some of the Windward Islands were not then in existence. The sea also covered large portions of Central America, including considerable lengths of the present watersheds in Panama, Nicaragua, and Southern Mexico. Mr. Easton informs us that the greater part of the area of Panama, Costa Rica, Nicaragua, and Honduras lies below an altitude of 500 feet; and that a submergence of that extent would open several channels between the Atlantic and Pacific Oceans. Thus, the summit-level of the Panama Canal is 459 feet above the sea, the dividing ridge at Nicaragua is only 170 feet, and at Leon in the same state only 212 feet. Parts of Guatemala and the whole of Yucatan

* Journ. Roy. Geogr. Soc. vol. i. (1832) p. 70; confirmed by Capt. Robt. Fitzroy, *op. cit.* vol. xx. (1851) p. 177.

would also be submerged by a depression of 500 feet, and much of Mexico near the isthmus of Tehuantepec; for, according to the data in Mr. Easton's possession, only about a mile of the watershed in the pass of Tehuantepec rises above 500 feet.

A submergence of 1000 feet would, therefore, cover some breadth of the Tehuantepec isthmus, and would leave little of Panama and Costa Rica above the sea; Nicaragua would be broken up into a group of islands, and parts of Honduras and Guatemala would form larger islands rising from 2000 to 3000 feet above the waves.

Now a thousand feet is only half the amount of the elevation indicated by the raised reefs of the Antilles; hence we reach the important conclusion that, for a long period of time, no land connexion existed between North and South America, Central America then forming a group of islands which might be regarded as merely a western part of the Caribbean Archipelago. In connexion with this supposition, it is interesting to note the fact that the fauna and flora of the Greater Antilles (Cuba, Jamaica, &c.) have closer affinities with those of Central America than with those of Florida or of South America.

The severance of North and South America at some epoch in Tertiary time is by no means a new suggestion, but we believe that this is the first occasion on which the idea has been discussed in connexion with definite geological evidence, pointing to a comparatively recent date for the sundering of the two continents.

The question has hitherto been obscured by the supposed Miocene date of so many of the West-Indian deposits, and even Prof. Alex. Agassiz, in his most recent publication ("The Three Cruises of the 'Blake'"), seems to have missed seeing the possibility of such recent communication between the Pacific and Atlantic Oceans. In his fifth chapter he specially discusses the relation of the American and West-Indian faunas, and indicates the connexion which would have existed on the assumption that at some previous period the whole region stood 3000 feet *higher* than it does now. He does not give any geological evidence for this supposition, but merely speculates upon the geographical conditions which would exist if at any previous period the 500-fathom line formed a coast-line. The idea was, in fact, suggested by the hydrographical survey of the region carried on by the "Blake" Expeditions, and we should not have referred to it had he not strangely included the possibility of a communication with the Pacific in his hypothetical restoration.

After showing that such an elevation would unite Florida to Cuba, and leave only very narrow passages at certain points along the Antillean chain, he says:—"At the time of this connection, if it existed, the Caribbean Sea was connected with the Atlantic only by" (certain passages mentioned) . . . "The Caribbean Sea, therefore, must have been a gulf of the Pacific, or have been connected with it by wide passages, of which we find the traces in the Tertiary and Cretaceous deposits of the Isthmus of Darien, of Panama, and of Nicaragua."

His words on this subject are not so clear as could be wished. The Tertiary deposits of Panama belong to a period of greater depression, and this is not likely to have been contemporaneous with an elevation of the Caribbean region, especially as similar Tertiary deposits occur in that region. On a previous page he states that such an elevation (*i. e.* of 500 fathoms) would almost unite Jamaica to Honduras and Nicaragua; *a fortiori*, Nicaragua and Panama would have been 3000 feet higher than they are now. Finally, he admits that the geographical conditions which he indicates may never have existed. We certainly think they never did: there may have been a time when the coast-line of the whole region coincided approximately with the 500-fathom line, but we do not believe that depression in Central America coincided with elevation in the Antilles.

We think that biologists require to be cautioned against assuming the former connexion of islands with continents on the basis of hydrographic evidence, unless it is supported by geological evidence of subsidence, for it is obvious that the shallowness of an intervening sea may be due to recent elevation. In the case of the Antilles, there is no evidence for the idea that the ridge on which the islands stand has been land in Pleistocene time, nor is the present distribution of animals on the islands such as to suggest a continental connexion of later date than the Miocene period. There is nothing clearer in the geological history of the West Indies, so far as it is at present known, than the fact that a great depression began in a mid-Tertiary or Miocene period, and continued through Pliocene times, and that this was succeeded by a movement of upheaval, which lasted down to very recent times.

We think that the shallowness of the sea between so many of the islands, and between Florida and the Bahamas, is due to recent upheaval, and that before this movement commenced there was no connexion between the two Americas, the intermediate Antillean region being an archipelago of islands separated by deep channels and waterspaces.

The limited terrestrial fauna of the West-Indian Islands, and the occurrence of certain genera which may be regarded as ancient types, confirm the geological evidence for the long-continued isolation of the Antillean area. The peculiarities of the fauna and flora of Central America are also capable of explanation on the hypothesis that the higher parts of that area were, until a recent period, part of the isolated Antillean archipelago, and washed by a current which set in from the east.

Moreover, the relations of the modern marine Caribbean fauna to that of the Pacific are in entire accord with our belief that the separation of the two regions is of very recent date. The following observations of Prof. Alex. Agassiz are interesting in this connexion *:—
"The resemblance of the fauna of the Gulf of Mexico and of the Caribbean to that of the Pacific was noticed by writers, even at a

* "Three Cruises of the 'Blake.'" Bull. Harvard Mus. vol. xiv. (1888) p. 157.

time when the materials available for comparison included but little beyond the littoral fauna. From the results of the deep-sea dredgings we have become quite familiar with the extent of this resemblance. In fact the deep-sea fauna of the Caribbean and Gulf of Mexico is far more closely related to that of the Pacific than to that of the Atlantic. Before the Cretaceous period, the Gulf of Mexico and the Caribbean were undoubtedly in freer communication with the Pacific than with the Atlantic Ocean, so that, notwithstanding the presence of a number of Atlantic types, the characteristic genera were common to the Pacific. Many of the genera have remained unchanged since the separation of the Atlantic from the Pacific by the elevation of the Isthmus of Panama and the Mexican Plateau."

In this and succeeding passages, Prof. Agassiz constantly assumes that the elevation of the Isthmus took place at the close of the Cretaceous period, but there is nothing among the few geological facts which he mentions that can be regarded as a basis for such a view. Moreover, the resemblance of the Caribbean to the Pacific fauna would not be explained by intercommunication in Cretaceous times. It is surely an indication of free communication between the two oceans at a much more recent date, so recently, in fact, that the Atlantic forms have not yet been able to displace the descendants of the Pacific types.

Finally, we are led to consider how far the existence of such geographical conditions in the Caribbean region must have affected the physical conditions of other regions, and particularly those of the North Atlantic, by preventing the present diversion of the great Equatorial current and the consequent formation of a Gulf-stream.

As everyone knows, the Gulf-stream is produced by the impingement of the Equatorial current upon the coast of Central America; but when, instead of the present continuous coast-line, there were only a series of islands with broad channels of 300-fathoms' depth between them, the great equatorial current must have passed through these channels into the Pacific Ocean.

It is not unlikely that the islands caused a separation of the current into two branches, one curving southward to join the Equatorial current of the South Pacific, the other passing in a W.N.W. direction to join the north Equatorial current. There is some positive evidence for the existence of the south-westerly current over the Isthmus of Panama in the West-Indian element which is observable in the fauna and flora of the Galapagos Islands. Mr. Alfred Wallace * has explained the peculiarities of these islands on this very hypothesis. He says :—"These facts are explained by the past history of the American continent, its separation at various epochs by arms of the sea uniting the two oceans across what is now Central America (the last separation being of recent date, as shown by the identical species of fishes on both sides of the isthmus), and the influence of the Glacial epoch in driving the temperate flora southward along the mountain-plateau. At the time when

* 'Island Life,' p. 277.

the two oceans were united, a portion of the Gulf-stream may have been diverted into the Pacific, giving rise to a current, some part of which would almost certainly have reached the Galapagos, and this may have helped to bring about that singular assemblage of West-Indian and Mexican plants now found there." To the evidence of the plants may be added the singular fact that since Mr. Wallace wrote his "Island Life" gigantic land-tortoises similar to those of the Galapagos have been found in a sub-fossil state in one of the Antilles.

The consideration of the different physical conditions which must at the same time have prevailed in the North Atlantic is a still more interesting problem for British geologists. It is possible that a small circulatory system, similar to that which occurs in the North Pacific, may then have existed in the southern part of the North Atlantic between Africa and Florida, but it would be on a comparatively small scale, and any small offshoot that it may have sent toward the coasts of Europe could not have exercised much ameliorating influence on the climate of those coasts.

The Arctic currents must have been all-powerful in the Atlantic north of lat. 40°, and such conditions are sufficient to account for the extreme rigour of the Glacial period in the British Islands and Northern Europe. We are not here suggesting a geographical explanation of the Glacial period, because the evidences of that period occur over the whole of the northern hemisphere, but it has often been pointed out that, in the absence of the Gulf-stream, Britain would be left with the climate of Newfoundland and Labrador. This very absence of a Gulf-stream, which has only hitherto been suggested as a possibility, follows as a necessary consequence from our restoration of Caribbean geography in early Pleistocene time, and that is based on definite geological facts.

The nature of the deposits which were formed during the great period of submergence that preceded the upheaval confirms the theory of previous open communication with the Pacific, and of these deposits we hope to treat in a future paper.

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## APPENDIX I.—*On the* MINUTE STRUCTURE *of some* CORAL-LIMESTONES *from* BARBADOS. By WILLIAM HILL, Esq., F.G.S.

[PLATE IX.*]

The following is a brief description of the minute structure of the coral-rocks of Barbados which have been sent me for examination; some were obtained by Mr. Jukes-Browne, and some more recently procured by Mr. Edw. Easton, C.E., from the shafts and tunnels made by the Barbados Water-Supply Company.

They are, as a whole, hard white crystalline limestones, generally full of cavities, caused apparently by the solution of some of the calcareous structures of the many organisms of which the rocks were formed.

It is hardly possible to say, from a microscopic examination only,

* This plate is presented by Mr. Hill.

whether any particular sample was part of an outer reef, formed under the lash of the breakers, or whether the materials were deposited in the quieter waters of the inner edge, in lagoons, or on the beach, but the limestones examined present marked differences of structure which are probably due to variation of the conditions under which they accumulated.

Examined in thin sections under the microscope they present four varieties of structure:—

1. Rock consisting of fragments, generally recognizable as coral, with many portions of a nullipore, set in a matrix which is now finely granular calcite. No foraminifera. (Pl. IX. fig. 1.)
2. Rock formed of moderately small particles, more or less closely packed, of a previously consolidated material, with many portions of a nullipore and a few foraminifera, the whole embedded in a matrix which is now granular calcite. (Pl. IX. fig. 2.)
3. Rock consisting of the fragments of a considerable variety of calcareous organisms. The matrix is now either granular or crystalline calcite. (Pl. IX. fig. 3.)
4. Rock consisting of definite separated grains cemented by pure crystalline calcite.
   (*a*) Largely formed of rounded fragments, exhibiting either definite organic structure, or that of a previously consolidated calcareous mud. (Pl. IX. fig. 4.)
   (*b*) In which the tests of *Amphistegina* are more numerous than the rounded grains. (Pl. IX. fig. 5.)

In the first variety of the coral-limestone the fragments which are angular, and show for the most part a true coral-structure, are set in a matrix of calcareous mud, and form as it were a fine breccia. They are often perforated by minute tubules similar to those made by boring algæ in recent corals.

The original character of the mud is entirely obscured by the minutely granular crystalline structure which has been superinduced in this matrix by the infiltration of calcite; but I have found that fine calcareous muds, which have become crystalline, always present a similar translucent and finely granular structure when seen in thin sections under the microscope, and it appears to be the usual condition of such mud when infiltrated by crystalline carbonate of lime. Portions of a nullipore (a *Lithothamnion*), usually showing an unbroken and continuous bounding edge of growth, form very prominent objects, and occupy a considerable area in the sections.

There are no foraminifera, and the structure of no other calcareous organism than coral and *Lithothamnion* appears in the specimens which I have examined.

Of this class there are two specimens, one from the surface 300 feet above sea-level at Bannatynes, and another from a quarry 700 feet above sea-level at Groves.

This last specimen contains branches of coral varying from half

an inch to an inch in diameter. These show a structure similar to the dead *Porites* * from the shore, a specimen of which was sent me for comparison.

The interstices of the coral were becoming filled with crystalline calcite, and the network of the coral itself seemed changing to granular crystalline calcite. In this specimen the minute structure of the angular coral-fragments is not so clear as in the preceding.

In the second variety the material of the rock consists largely of particles either of an already consolidated mud which appears to be in the condition of the matrix previously described, or of minute portions of *Lithothamnion* or of coral or shell. In size they vary, some being minute, others sufficiently large to be described as grains. In shape they are usually angular, but are sometimes more or less rounded, and as a whole they are optically denser than the surrounding matrix. Though generally closely packed, they are not all equally so, and in some parts of the same section they are more separated than in others.

The matrix is finely granular calcite, but coarser in grain than in the preceding variety, and therefore more transparent. It is hardly possible to say whether this was originally fine mud in which the granular structure has been superinduced by filtration, or whether it is calcite deposited between the interstices of the separate fragments.

The *Lithothamnion* is more abundant in this than in any other variety of the coral-rock; in some sections little else but its structure is seen, small interstices being filled-up with material similar in character to that of the mass of the rock. The area occupied by it is so large, and there is so little evidence of breakage, this too in a rock which itself consists of the comminuted fragments of an already consolidated deposit, that I believe much of the nullipore occupies still, in relation to the surrounding material, the position in which it grew, and may be considered as being in place.

There are but few foraminifera; amongst them may be recognized *Amphistegina*.

Small cavities which occur in this and in all the coral-rocks bear some relation in their size and shape to the fragments of calcareous organisms and other particles embedded in the matrix; they are probably caused by the solution of some particular fragments which yield to the action of acidified water more readily than others. Some cavities doubtless originate in the actual structure of the fragments of coral, polyzoa, or foraminiferal cells, &c.

In all the coral-rocks there is evidence that organic calcite, *i. e.* fragments of calcareous organisms and mud formed by the detrition of such organisms, is more easily soluble than precipitated calcite, and I infer that the cavities often indicate the position occupied by calcareous fragments or mud. The cavities become again filled

* Dr. Hinde kindly examined sections of these rocks, and pointed out the coral-structure with minute borings; he considered that the included sponge-branches were without much doubt *Porites*, and he recognized also the structure of *Lithothamnion*.

with calcite, in some cases pure and crystalline, in others granular; but nearly always the infilling material is in coarser crystals than the surrounding matrix, and the outline of the original fragment is to a certain extent preserved.

Specimens showing the structure of the second division come from three localities. There are several from Castle Grant, where the surface is over 1000 feet above sea-level, one from a shaft at Lightfoots and another from a shaft at Bath; the mouth of the latter is 400 feet above sea-level, and the specimen was obtained about 90 feet down. There is no important difference in any of these specimens.

The striking feature in the structure of the third description of coral-limestone is the variety of the organic fragments of which it consists. There can be recognized pieces of coral, nullipore and shell, echinoid spines, plates, and ossicles, many species of foraminifera, amongst which *Amphistegina* is common, and lastly portions of polyzoa; the whole rock is in fact a collection of the fragments of the many organisms which exist on the coral-reefs.

The size of the fragments differs as usual in the different specimens of rock of this character; in some of them a part may be too small for identification; in others, where the fragments are larger, the structural details of each fragment are often well shown.

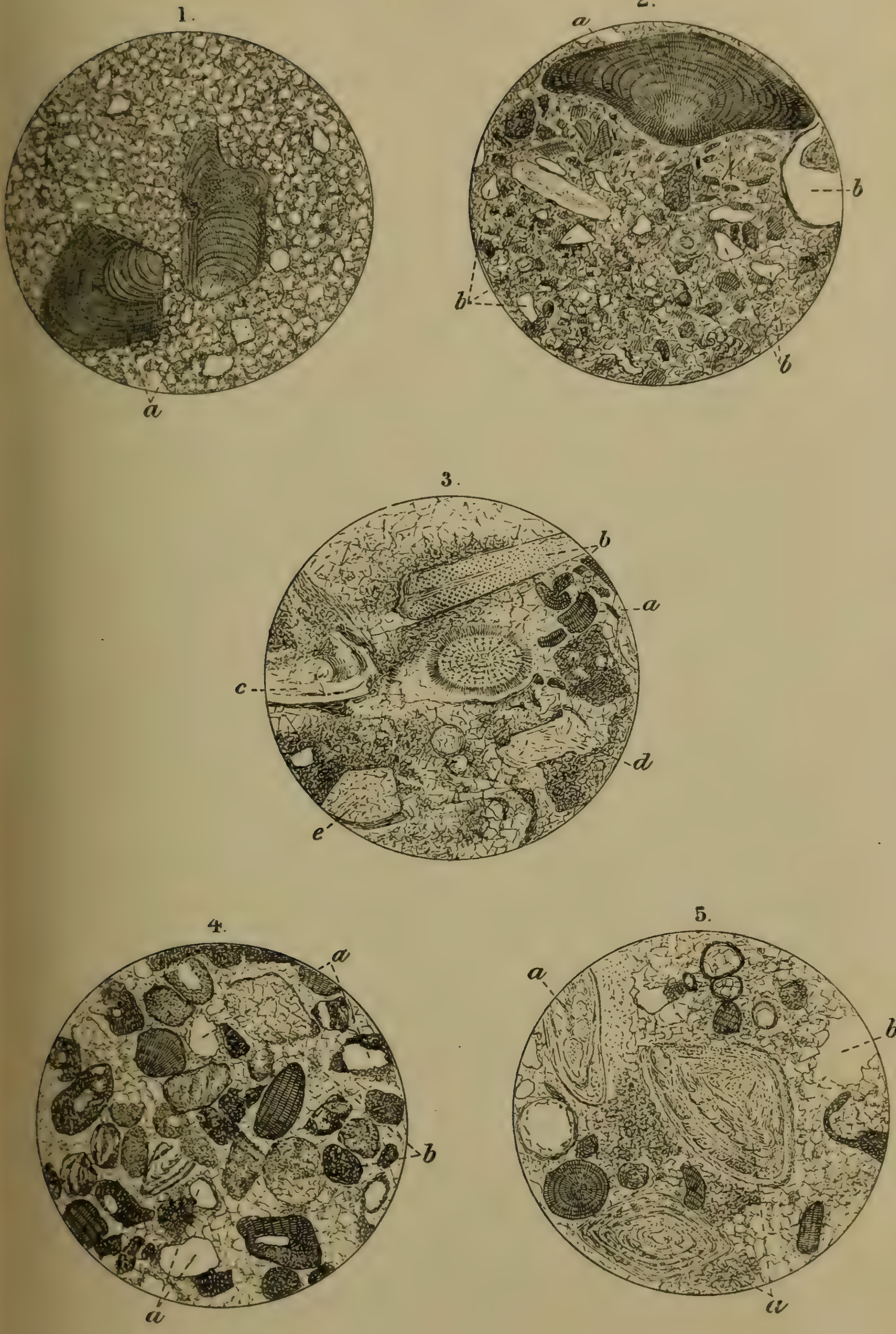
The matrix varies; in two specimens it appears to be fine calcareous mud, but in three others the material investing the fragments is pure crystalline calcite.

As before, the rock is full of cavities; their outline often leaves little doubt that they have resulted from the solution of one or other of the enclosed fragments. Whether it is some particular class of fragments which first disappear, or whether the solution of fragments is accelerated or retarded by physical causes which determine the course of percolating water, I cannot say.

There are five specimens which show the structure of this division. Two are from Plumtree Gully from a shaft, at about 45 feet below the surface; a third is from a boring at Lightfoots; a fourth is from another shaft at Plumtree Gully, 30 feet from the surface; and the fifth from No. 3 Shaft, Rock Dundo, the mouth of which is 303 feet above sea-level, and the specimen was obtained 44 feet from the surface. The first three closely resemble each other, and they are the softest and least crystalline of the whole series. The organic fragments are fewer and smaller than in the two succeeding specimens, and the matrix of fine calcareous mud is less altered than usual, the infiltration of crystalline calcite being hardly complete, but in this respect the specimens show some variation. In the next two the fragments are coarser, the cementing material is chiefly crystalline calcite, but there are inclusions of calcareous mud; the whole is, however, thoroughly infiltrated with calcite, and is hard and crystalline.

Of the foraminifera seen in these rocks *Amphistegina Lessonii* is a prominent form.

In the fourth division the rock is practically a coral-sand




CORAL-LIMESTONES OF BARBADOS.

cemented by pure crystalline calcite. The grains of this sand, when seen in section, are subangular or rounded, and separated from each other. Their size is about that of mustard seed or a little smaller, their dimensions differing in various specimens, but the relative size of the grains in each specimen is remarkably even. They show the structure of coral, shell, nullipore, &c.; in fact, all the calcareous organisms noted in the last division, of which they are the rolled fragments; but they include also pieces of consolidated mud.

The localities from which they were obtained are as follows:—

Plumtree Gully, E. of Endeavour, 45 feet below surface.

Plumtree Gully, E. of Endeavour, 30 feet below surface, 680 feet above sea-level.

Ellis-Castle Well, at a depth of 130 feet from the surface.

Cane Garden, from a tunnel 120 feet below the surface, and 500 feet above sea-level.

Thicket Estate, from a shaft 87 feet from the surface.

The *Amphistegina*-rock (*b*) was obtained from Vaughan's Estate, N. of Horse Hill.

The fact noted on p. 245, that organic calcite is less stable than precipitated calcite, is nowhere shown better than in these rocks (*a*). The specimens from Plumtree Gully are from a recognized waterway in the coral-rock. It is here quite porous from the number of individual grains which have disappeared. All the cavities correspond exactly with missing grains, and some have become refilled with crystalline calcite; the outline of the original grain being preserved by a kind of edging of finely granular calcite, which seems to surround each grain (see fig. 4, Pl. IX.).

(*b*) Only one specimen of this rock occurs. "It is from a block of very hard white coral-rock, as large as a negro's cabin, lying on the surface on Vaughan's Estate at a height of over 700 feet above sea-level." A thin section shows that this rock consists mainly of foraminifera. The slide was sent to the late Dr. H. B. Brady, who thus wrote of it:—"The prevailing foraminifer is *Amphistegina Lessonii* (D'Orb.); it is a fine example of *Amphistegina*-rock, the shells now being mingled with coral-sand and the deposit formed in shallow water, at not more than 8 fathoms and probably less than one."

As in the above, the matrix is pure crystalline calcite.

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Coral (?) mud, Codrington College. This is from a bed which occurs at the base of the coral-rocks, between them and the Oceanic series. The material is unconsolidated and is as fine as flour. Seen under the microscope in glycerine, it appears to be made up exclusively of minute calcitic crystals of a somewhat complex rhombohedral shape, not all precisely alike in outline, but sufficiently so

to give a naviculoid appearance to the whole of the particles. In their longest axis the largest measure ·02 millim. diameter, and from this they diminish to minute atoms.

There are no foraminifera, radiolarians, or coccoliths in the material sent me, nor any of the organic fragments such as occur in the coral-rocks.

## EXPLANATION OF PLATE IX.

Coral-rocks of Barbados. (× about 15.)

Fig. 1. Coral-rock, Bannatynes. The angular fragments show the structure of coral; *a*, portion of *Lithothamnion*.
2. Coral-rock, Castle Grant. *a*, *Lithothamnion*; *b*, cavities.
3. Coral-rock, Gully, E. of Endeavour. *a*, fragments of *Lithothamnion*; *b*, spine of an Echinoderm; *c*, foraminiferal fragment, probably of the genus *Amphistegina*; *d*, coral fragment; *e*, shell fragment.
4. Coral-sand rock. *a*, cavities; *b*, *c*, cavities apparently refilled with calcite, showing outline of original sand-grain.
5. *Amphistegina*-rock. *a*, *Amphistegina Lessonii*; *b*, cavity.

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## APPENDIX II.—*On the* Structure *of* White Limestone *from* Jamaica. By William Hill, Esq., F.G.S.

Five specimens of the white limestone of Jamaica were sent by Mr. C. Barrington Brown to Mr. Jukes-Browne, who kindly forwarded them to me for examination and comparison.

Their structure, when seen in thin sections under the microscope, shows that they are limestones formed by the accumulation of the débris of calcareous organisms, and two at least strongly resemble certain varieties of the Barbados coral-rocks.

Of these two, one specimen from Mile Gully, Manchester county, consists of angular fragments, similar in size and shape to the pieces which can be recognized as coral in the first division of the Barbados rocks, and these are set in a matrix of what was, in all probability, fine mud, but is now finely granular calcite (see p. 244). The structure of the fragments and the mud is obliterated by the general crystallization of the deposit; this, however, is paralleled in one of the Barbados specimens.

In the second, also from Mile Gully, Manchester county, the structure is very similar to that of the third division of the Barbados coral-rock. This limestone seems to have been made up originally of rather large organic fragments set in a matrix of fine mud. For the most part the structure of these fragments is lost, their outline only being shown by patches of clear crystalline calcite; but there can still be identified fragments of the same *Lithothamnion* as that which is seen in all the coral-rocks of Barbados, and there are also fragments of foraminifera which are probably referable to the genus *Amphistegina*. The specimen contains moreover many ossicles of a recent star-fish.

Two other specimens, one from Belmont, St. Elizabeth, and the other from Mile Gully, appear to have originally consisted of calcareous organic fragments closely packed. The majority of these now appear only as patches of clear crystalline calcite in a matrix in which the calcite is granular.

One or two can be seen to be echinoid plates or ossicles, but the crystalline condition of the whole mass makes their identification and comparison with the fragments in the Barbados rocks no longer possible. The fifth specimen, from Belmont, St. Elizabeth, is entirely clear crystalline calcite, in which are outlined many foraminifera, the structure of all other constituents of the rock being lost. The predominating form is *Orbitolites* *. This rock will not compare with any of those from Barbados.

Another specimen of a white limestone from Hanover county, Jamaica, was kindly sent me by Col. Feilden; this, however, proved to be an Oceanic deposit, and a slide of a similar rock was sent me at the request of Mr. Jukes-Browne by Messrs. Watson. Col. Feilden was also kind enough to send me some oolitic coral-rock from Nassau, Bermuda. This is a true oolite, and no coral-rock of Barbados that I examined is in the least like it.

## Discussion.

Rev. Edwin Hill said that a submergence of the Isthmus had often been thought of in connexion with the Glacial question; he had hitherto understood that evidence was against this. Thus the views of the Authors were extremely interesting.

Mr. Attwood remarked that his frequent visits to Barbados, Trinidad, and most of the Antilles, combined with an intimate knowledge of the Venezuelan coast, the Isthmus of Panama, Colon, Costa Rica, Jamaica, and Hayti, had afforded him opportunities of observing the general geological features of the above-mentioned places, and he could confirm the Authors' opinion in regard to a general uprise of land having taken place in recent geological times in the afore-mentioned countries. The evidences for this were, in his opinion, undoubted, but he thought further evidence should be elicited as to the date of this movement. He preferred to leave the Gulf-stream theory alone until further information had been collected.

Mr. J. W. Gregory asked what evidence the Authors adduced of the submergence of the Isthmus of Panama, as none such appeared in the surveys made for the Canal. He suggested that the difference between the faunas on either side showed that any connexion must have been much earlier than these Pleistocene reefs, of which all the species are living. The evidence of the land-fauna of the Windward Isles supported this.

Mr. W. Hill could say little with regard to the coral-rocks of Barbados, and the general questions arising from the paper.

* Dr. Hinde kindly identified this.

Mr. Jukes-Browne had sent him many specimens of the coral-limestone for examination, and on these he had written two short appendices to the paper.

The rocks present some marked variations in structure, and, so far as one can judge from hand-specimens and thin sections, it would appear that the limestones described by Prof. Dana in his "Coral and Coral Islands" as the outer and inner reef-rock and the beach-sand rock are represented in the coral-limestones of Barbados.

Specimens of white limestones from Jamaica were also sent for comparison. Of these some seem to be oceanic deposits, but others are without much doubt coral-limestones, although the general details of structure are obscured by the crystallization of the whole.

Mr. Easton said that he had obtained the specimens of coral-rock and other rocks exhibited during works now being carried on under his superintendence. These works consisted of tunnels driven in to bring to the surface the water collected in more or less defined channels after percolating through the coral-rock. At least five levels exist in which the water is found generally flowing on the top of the lower beds under the coral-rock, which forms in each case an escarpment of about the same height These escarpments all bear evidence of having once been sea-coasts, and having been successively raised to their present level. He had great pleasure in submitting the specimens exhibited, and hoped to obtain more.

Dr. Blanford doubted whether the evidence produced was sufficient to justify the assignment of the coral-reef beds to the Pleistocene, for the proportion of recent species and the amount of denudation described were compatible with greater antiquity. The relations of the land-fauna in North and South America—for instance, the distribution of the *Cervidæ*—did not support the view that the two continents were distinct throughout the later Tertiaries, and were not united until the latter part of the Pleistocene. It should be remembered that the removal of the Isthmus of Panama could not have greatly influenced the phenomena of the Glacial epoch; the North Atlantic would have been rather colder, but this would not explain the glaciation of other parts of the world, such as British Columbia.

The President remarked that the details supplied in the paper formed an important addition to the literature of the coral-reef question, showing as they did clear evidence of the elevation of old coral-reefs. He thought the speculations appended by the Authors as to the changes in the level of the South-American continent and Central America somewhat out of place, and hardly warranted by any of the observations recorded in the paper. No trifling submergence of the Isthmus of Panama would serve to divert the great Equatorial current into the Pacific Ocean. Unless the downward movement had been more serious than the Authors seemed to suppose, the bulk of the current would still sweep round into the Gulf of Mexico, only the upper waters passing into the Western Ocean.

16. *On* Nepheline-Rocks *in* Brazil.—Part II. *The* Tingua Mass. By Orville A. Derby, Esq., F.G.S., &c. (Read December 17, 1890.)

In a former paper under the above general title (Quart. Journ. Geol. Soc. vol. xliii. 1887, pp. 457 *et seq.*), the distribution, so far as it is at present known, of the nepheline-bearing rocks in Brazil was given, together with a somewhat detailed description of the Poços de Caldas locality. Since that time three important petrographical papers relating to this group of rocks have appeared *, one of which is accompanied by a detailed geological description of the insular, and presumably later, eruptive mass of Fernando de Noronha.

In this and subsequent papers, it is proposed to treat of the other continental localities, with special reference to the geological relations and mode of occurrence of this interesting group. One of the localities enumerated in that paper—the Serra de Bocaina—should be eliminated from the list, as a recent examination shows it to be composed exclusively of gneiss and granite. The specimens reported to have come from this locality are probably from the neighbouring mass of the Serra de Itatiaia.

The peak of Tingua is one of the two prominent masses that break the somewhat monotonous, approximately even-topped outline of the Serra do Mar, as seen from Rio de Janeiro; the other being the well-known Serra dos Orgões. Of the two, the former, although of less elevation (1600 as compared with 2232 metres), is, to the geological eye at least, the most striking, since its topographical features, and more particularly its conical form and apparent distinctness from the range to which it belongs, are more suggestive of a difference in geological structure and origin. The Serra dos Orgões, consisting of gneiss and granite, which are everywhere the characteristic components of the range, forms an integral part of it; the eruption of the immense boss of granite (granitite) that constitutes the highest points probably dating from or near the epoch of upheaval that gave the range, as a whole, its present form and character. Tingua, on the other hand, is a *parasitic* or *superimposed* mountain, according to the nomenclature of Von Richthofen, the product of a purely local eruption of very different character and of much later age †.

Although overtopping by some 500–600 metres the mean elevation of the Serra do Mar in its vicinity, the Tingua peak is not even

* Graeff, 'Mineralogische-petrographische Untersuchung von Elaeolithsyeniten von der Serra de Tingua,' Neues Jahrb. vol. ii. (1887).

Jordano Machado, 'Beitrag zur Petrographie der südwestlichen Grenze zwischen Minas Geraes und S. Paulo' [Poços de Caldas region], Tschermak's Mittheil. vol. ix. (1887).

Branner and Williams, 'Geology of Fernando de Noronha,' Amer. Journ. Science, vol. xxxviii. (1889).

† The very similar eruptive mass of Poços de Caldas is of late Carboniferous or early Secondary age.

placed on the main ridge of the range. At its back two small, but deep, longitudinal valleys—the São Pedro and Santa Anna—split the range up into three parallel ridges, of which the third is the main watershed between the river Parahyba and the sea, while the other two break down on the seaward side in the immediate vicinity of the peak. All of these are normal gneiss ridges. The outer two are narrow, with subparallel margins and a sharp angular crest, with a very uniform elevation of 800–900 metres. Near the extremity of the outer or São Pedro ridge, the uniformity of the crest is broken by the abrupt elevation of a saddle-like peak, which breaks down with the same abruptness to the normal elevation of the gneiss ridge on the other side. The eruptive mass, whose limits are approximately shown in the sketch-map (fig. 1), extends but slightly to the northward of the crest, and produces no prominent deflection of the inner margin of the gneiss ridge, or of the course of the river São Pedro that marks that margin. On the front side, however, it presents an enormous protuberance, which gives the peak, when seen from a distance, the appearance of an independent mass standing in front of the gneiss ridge, instead of resting upon and rising above it.

Seen from the São Pedro side, the peak presents a steep, straight, bastion-like face in the same plane as that of the gneiss ridge, with two prominent conical points—the peak proper and the lower Santo Antonio peak, united by a sort of curtain. On the opposite side, each of these points is seen to be at the junction of secondary transverse crests with the main crest. Of these, the one extending from the main peak is the most important, and is crowned by a number of minor peaks, one of which projects towards a lateral ridge of the Santo Antonio peak in such a manner as to nearly enclose a deep amphitheatre-like central depression—the upper valley of the Rio do Ouro. From certain points of view, the aspect of this valley is exceedingly suggestive of a crater, which, taken in connexion with the general conical form of the mass and the character of its eruptive rocks, is probably not without significance.

The river São Pedro passes the back of the peak at an elevation of 600–700 metres, but descends rapidly, and reaches a low marshy plain but slightly elevated above sea-level before escaping past the end of the outer gneiss ridge. This plain, of very recent formation, stretches along the front of the Serra do Mar, from the Bay of Rio de Janeiro on one side to the sea on the other. It is drained by the rivers Iguassú, flowing to the Bay of Rio, and Guandú, flowing to the sea. The former—a sluggish lowland river—receives, through several small streams, the drainage of the broad south-eastern flank of the Tingua peak. The latter issues from a broad gap near the centre of the outer rim of a considerable canoe-shaped longitudinal valley between parallel ridges of the Serra do Mar, of which the river Santa Anna occupies the eastern half. It receives the São Pedro from the back of the peak, and the Rio do Ouro and the Santo Antonio from the front. The most characteristic stream of the peak proper is the Rio do Ouro, coming from the central crater-

like depression. The Santo Antonio drains the small south-western flank, and receives, through the Limeira, the drainage of the short section of the gneiss ridge that projects beyond the peak. Of the streams falling into the São Pedro, the most important is the Barra, whose course marks approximately the western limit of the eruptive mass on that side.

For a mountain in the Brazilian forest-region, the peak is unusually accessible to geological examination, owing to the derivation of its waters for the supply of the city of Rio de Janeiro. A tram-line, 53 kilometres long, leads from the city to the Rio do Ouro reservoir; while a branch skirts the south-eastern face to

Fig. 1.—*Sketch-map of the Tingua massif.*


Conceição, and another passes around the western end of the gneiss ridge to the river São Pedro. Nearly all the streams of the front side, together with the São Pedro, have been dammed near the 100-metre level, and connected by pipe-lines, shown by the heavy dark trace on the sketch-map* (fig. 1). The numerous cuttings of the

* The basis of this sketch is the large map of the streams, roads, and pipe-lines kindly furnished by the waterworks engineers, to whom I am greatly indebted for uniform courtesy and hearty co-operation in the course of this investigation. To give a better idea of the topographical features, 200-metre contour-lines, without pretensions to accuracy, have been sketched in from a

tram- and pipe-lines afford excellent opportunities for the study of the lower marginal zone. Still more important is a high-level ditch, cut for a provisional supply at a time of water famine, near the 600-metre level, for taking the waters of the São Pedro over the top of the ridge. This gives an almost absolutely continuous section of rock *in situ* (in great part decomposed) for a distance of 16 kilometres. Unfortunately, however, it barely touches the eruptive mass of the peak proper, at two points of no special interest. A paved road from Conceição across the ridge to the east of the peak also affords excellent sections. Outside these lines everything is covered with heavy forest and dense jungle, and exploration is difficult and unsatisfactory. Trails have been cut from the summit-level of the paved road to the highest point of the peak, and from the Rio do Ouro reservoir around the western flank of the peak to the upper (provisional) dam of the São Pedro, and along the side of the Rio do Ouro valley to a point well within the central crater-like depression. The stream-beds have also been followed for a certain distance; but it was found that in the most interesting portions they are so obstructed by falls and loose boulders that one is obliged to take to the woods, and thus lose all opportunity for geological observation.

The fundamental rock of the region is a biotite-gneiss, generally coarse-grained and porphyritic, like the characteristic variety of the mountains about Rio de Janeiro. This is cut by numerous dykes of biotite-granite (granitite) and diabase, such as are common in all the Brazilian gneiss-regions that have been examined, and which, being clearly anterior to the eruptions that produced the peak, need not be more fully considered here. Very small dykes of muscovite-granite, decomposed to kaolin, also occur rarely.

In the peak proper, the predominant type is the orthoclase-nepheline combination, either holocrystalline, as foyaite*, or porphyritic,

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limited number of aneroid observations. The heavy black of the pipe-lines and ditches, and the light-dotted trace of the roads and trails, show the lines that have been examined; while the heavy-dotted trace shows the approximate outline of the area occupied by the eruptive rocks and of the peak proper. Outside this area, the contoured portions are gneiss, and the light parts mainly alluvial flats, with detached outliers of gneiss and granite.

* To avoid the cumbersome and misleading designations derived from *syenite*, it seems convenient to employ some one of the numerous simple and non-committal names that have been applied to this group of rocks as a general name for the whole. Of these, *foyaite*, as defined by Prof. Rosenbusch (the hornblende-, augite-, or ægerine-bearing members of the group), applies best to the Brazilian types, and seems best adapted as a general denomination. Aside from this, there is a certain propriety in retaining a name of Portuguese origin for a group best known through occurrences in Portuguese-speaking countries—Portugal, Cape-Verde Islands, and Brazil. In his recent paper in Tschermak's Mittheilungen (vol. xi. p. 160), Prof. Rosenbusch appears to sanction this usage in the term *Foyaitmagma*. The term *Tinguaite*, proposed by Prof. Rosenbusch for the phonolitic types of the Brazilian orthoclase-nepheline rocks, is not here adopted, as it seems to be based on a misapprehension, for which the writer is responsible, since, in the collection sent to Heidelberg, it happened that only dyke-phonolites were represented, thus creating the impression that the typical effusive forms did not occur in the Brazilian localities.

as phonolite. Aside from this type, there is a group of basic rocks, of basaltic aspect, which is thus far only known in small dykes, but which may be suspected to occur in more important masses in some of the unexplored portions of the mountains.

As at the Poços de Caldas locality, there is abundant evidence that the foyaite and phonolite are but different phases of the same original magma. In fact, part of the distinctly granular rocks present as well-marked a division of the crystalline elements into two generations, as phenocrysts (*Einsprenglinge*) and groundmass, as do the typical phonolites, and might either be considered as phonolites, with a coarsely granular groundmass, or as foyaites, with a phonolitic structure. For the study of the origin of the eruptive mass, the distinctively phonolitic type is in its modes of occurrence the most instructive; it appears both in the form of dykes and as effusive sheets.

Only the dyke-phonolites, or loose masses that are presumed to come from dykes, have been found in a state of preservation such as to permit of satisfactory petrographical study. Among these, nearly all the prominent characteristics of mineral composition and structure may be observed. Both nephelinitoid and trachytoid phonolites abound; while, as will be seen farther on, there is a tendency towards the leucite-phonolite type. The rocks of the first type frequently exhibit the ocellar structure; while those of the second have a well-marked fluidal structure, and appear to pass into true trachytes. Fragments of this last type are comparatively rare, except in the bed of the Santo Antonio, where they have been traced to a dyke, 2 metres wide, which cuts the gneiss a hundred metres or so above the dam. A peculiar feature of some of these rocks is the presence of polygonal granular inclusions or aggregations, which, being common also to the foyaites, will be discussed after the description of that group.

A considerable number of phonolite dykes have been seen in the cuttings through gneiss outside the area of the peak proper; and, in one or two instances, they have been met with at a distance of several kilometres away from the eruptive centre. These peripheral dykes of phonolite are seldom less than one, or more than two, metres in width, the dykes that are notably less than a metre in width being universally, so far as present observations go, of a more basic type of rock. Within the eruptive area—that is to say, the area where foyaite occurs—the dimensions may be greater, one dyke, forming a fall on the small river Sabino, being over ten metres wide. In only two cases have phonolite dykes been seen cutting foyaite: one is at the very summit of the peak; the other in a loose block at the foot (see fig. 4, p. 261).

High up on the Rio do Ouro, and well within the crater-like depression, the river flows for a considerable distance (more than 100 metres at the least) over a mass of phonolite which is unquestionably effusive. The limits of the mass were not seen, but it was found extending laterally some scores of metres to the right, where it forms a fall on a branch stream. Although sufficient to form considerable cataracts in the river-bed, the rock is so decomposed

that it was impossible to obtain a specimen suitable for microscopic examination. Indeed, it was extremely difficult to detach any sort of specimen, as the rock is smoothed and rounded by the stream like a mass of stiff clay, and behaves like it under the hammer. A polished face of some of the harder pieces detached shows a typical phonolitic structure, with large and well-formed phenocrysts of felspar, completely kaolinized, and quadratic sections of a milky-white zeolite (?), which probably represents nepheline. Another specimen is a true tuff, with large and small rounded pebble-like fragments, in part granular, in part compact. On the water-worn walls of the cañon the tufaceous character of a large part of the mass is very apparent, fragments, up to the size of a man's head or larger, standing out very distinctly from the general mass. Some of these are coarsely granular, and appear to be foyaite; others are compact like phonolite. No line of demarcation between the part with inclusions (tuff) and the ordinary phonolitic type could be observed, since, if any such existed, it has been obliterated by the equal decay of the whole mass. The essential fact, however, is clear, that a true effusive rock here occurs, represented in part by fragmental eruptions, in part probably by a phonolitic lava-flow, although it is possible that the phonolite specimens may have come from a dyke traversing the mass of tuff. A complete analogy is thus established with the Poços de Caldas locality, where foyaite, phonolite, and fragmental eruptives occur so intimately associated that a truly volcanic origin, in the most restricted significance of the term, may safely be predicated for the whole.

This conclusion of a volcanic origin for the eruptive mass of Tingua, including its most characteristic rock-types—the foyaites, affords a ready explanation for a number of peculiarities of this rock, which are difficult to account for on the generally accepted view that it is a deep-seated rock (*Tiefengestein*), in the same sense as are, for example, the granites and ordinary syenites. These peculiarities are, as regards the Tingua mass, the mode of occurrence, the irregular (*Schlieren*) structure, and trachytic (phonolitic or porphyritic) habit. The last two points have been noted in other foyaite localities *; the first, so far as I am aware, has not received any particular attention.

So far as can be concluded from the examination hitherto made, the foyaite of the Serra de Tingua nowhere presents the characteristics of a dyke or boss. A complete circuit of the mountain has been made within a distance of 1–2 kilometres of the area in which foyaite is the predominant surface-rock, and often within it, without meeting a single mass of the rock *in situ*. The cuttings of the pipe-, tram-, and ordinary road-lines, amounting to some thirty kilometres or more of rock *in situ*, are uniformly in gneiss cut by innumerable dykes of granite, diabase, phonolite, and basalt, but without a single dyke of foyaite, although in scores of cuttings the latter rock is present in loose rounded blocks, resting on the

* See Rosenbusch, 'Mikr. Phys. Gesteine,' p. 92.

gneiss*. This is the more remarkable as the foyaite resists decay much better than the other rocks of the region, so that its absence cannot be explained by decomposition †. The central eruptive mass seems to be destitute of dyke-like apophyses, or these are represented by phonolite or basic rocks, and not by foyaite. The nearest approach to a dyke that has been seen is in an immense block below the lower São-Pedro dam, that stands between two blocks of gneiss, each of the three being the size of a small cottage, in such a way as to suggest a dyke decomposed along the contact. This exposure, and the patch of foyaite and phonolite blocks to which it belongs, are interesting from the lack of surface-connexion with the peak. Such a connexion, if it exists, should appear along the road up the São-Pedro valley or the high-level ditch, which, however, shows nothing but a few insignificant dykes of phonolite. This patch apparently represents a small independent (as regards the surface) centre of eruption.

In following up the stream-beds the same fact is noticed. These mountain-torrents, so choked as to be almost impassable with immense loose blocks, among which foyaite predominates over all other rock-species, nowhere, so far as examined, show this rock *in situ*. Their beds, even high up on the flanks of the mountain, are in gneiss or, as in the case of the upper section of the Rio do Ouro at the point visited, in effusive rocks, either phonolite or consolidated tufaceous material. The impression that one gets is that the foyaite blocks come from a bedded mass, broken down by undermining, rather than from a dyke or stock.

The long narrow ridge between the Rio do Ouro and the Santo Antonio confirms this impression. The surface everywhere bristles with projecting masses of foyaite. The rivers on either side flow over gneiss beds, and are choked with loose masses of foyaite. Here, if anywhere, an immense dyke, or stock, of the same rock should be met with in a cross-section of the ridge. Two such sections are presented. One is by a road passing, with a considerable cutting, through a gap near the end of the ridge. This shows gneiss

* On the main tram-line these blocks are only met with on the last two or three kilometres near the Rio do Ouro reservoir. None occur on the Conceição branch, nor on that of the São Pedro, except at the end near the dam. The road from the lower to the upper São-Pedro dam is free from them below the mouth of the Barra. From here along the forest-road up the São-Pedro valley, they occur at frequent intervals in large patches. The paved road over the ridge from Conceição has none from the summit down to the crossing of the Brava. The high-level São Pedro ditch has them above the mouth of the Barra and in the last two kilometres near the Santo Antonio, but for the rest of the distance (12 kilometres of continuous rock-exposure) not so much as a pebble was seen.

† The blocks in general have a decomposition crust of only 1–2 centimetres at the most. Special search was made for totally decomposed masses, for the purpose of obtaining rare accessory minerals by washing. Only a few such blocks, and these comparatively small, could be found. These were so tough and spongy as to retain their form, and require crushing with a hammer, whereas gneiss and granite in the immediate vicinity were so completely transformed into an earthy mass as to be readily reduced to mud and sand by the pressure of the fingers under water.

decomposed *in situ* under a soil-cap with loose blocks of foyaite. The other section is a tunnel, 300 to 400 metres long, for the passage of water to the storage reservoir on the Rio do Ouro. It is cut exclusively in gneiss, with a few insignificant dykes of basic rocks. A footpath over the top shows gneiss *in situ* for a few metres on the slopes above each tunnel-opening, and blocks of foyaite rising abundantly from the soil for the rest of the distance. It is clear that the foyaite, instead of piercing the gneiss, here rests as a sheet upon its surface. As the level of the gneiss rises rapidly in the stream-beds and lateral spurs of the mountain, the sheet of foyaite must have occupied an inclined position, sloping from the higher parts of the mountain to the lowlands at the base.

Outside the stream-beds and artificial cuttings, which only give access to the marginal zone of the eruptive mass, it is difficult, owing to the almost unbroken soil-cap covered with dense forest, to determine the true character of the exposures. The fragmentary condition of the foyaite is general, even over the surface of the summit of the peak, where the underlying rock is unquestionably *in situ*, though whether as a boss, dyke, or sheet could not be determined. On the flanks of the mountain over the elevated portions outside the stream-beds, the general surface-character of the exposures is that of boulder-trains, which might result from the broken-up outcrop of either a dyke or a sheet. The hypothesis of a continuous boss is excluded by the lack of continuity of the exposures in a horizontal plane. Something like half of the outer face of the Santo-Antonio peak has been traversed at about a quarter of its elevation. Occasional boulder-patches were met with, but for the most part the trail was over a reddish argillaceous soil, which must have come from the decomposition of some rock other than gneiss or foyaite. The former is excluded by the absence of quartz grains; the latter, by its mode of decomposition and its appearance at intervals as boulders. The greater part of the mass of the peak is here evidently formed of some easily-decomposed eruptive rock traversed by dykes or sheets of foyaite. The appearance, in the same section, of the effusive type of phonolite and tuff, so subject to decay that even in the bed of a mountain-torrent it is not well preserved, affords a clue to the probable nature of this rock, and at the same time suggests the hypothesis that, contrary to appearances, the foyaite plays a subordinate part in the composition of the Tingua eruptive mass, considered as a whole.

The evidence above presented of the occurrence of a large portion of the Tingua foyaites in sheet-like masses warrants a comparison with the Poços de Caldas locality, where this mode of occurrence is seen in great perfection in the foyaite mass cut by the tunnel, as described in a former paper *. This mass forms an irregular sheet, some 10 to 20 metres in thickness, inclined at an angle of 15°–20°, and cutting through a rock which is in part a volcanic conglomerate, in part apparently an imperfectly-individualized phonolite. It may be considered as lava, which, instead of being

* Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 466.

entirely subaerial, cut through the upper and imperfectly-consolidated deposits of a volcanic cone. It is interesting to note that this Caldas rock shows the same tendency to phonolitic structure and the same polyhedral segregations (pseudo-crystals), to be described farther on, as does the Tingua rock. It may also be remarked that, but for the railway cutting the mountain-side from top to bottom, the effusive types of eruptive rocks (tuffs and phonolitic lava-flows) would be no more prominent at the Caldas locality than they are at Tingua; while the extremely significant type of basic eruptives (leucitite) would have escaped observation altogether.

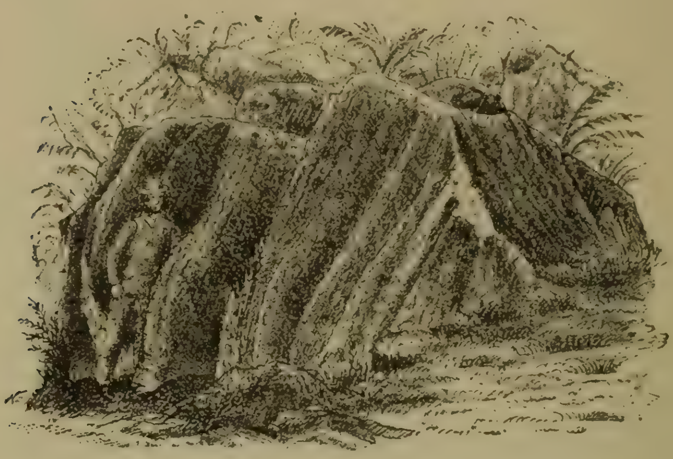
The general fragmentary condition of the Tingua foyaites, suggestive of a breaking-up through undermining of the eruptive masses, finds a ready explanation in the hypothesis above presented, which presupposes an underlying mass of easily-decomposed and presumably more or less incoherent material. In the marginal zone where the broken-up foyaite rests upon gneiss, this nonexistent cushion may have been, in part at least, the soft material resulting from the decomposition of the latter rock previous to the eruption. It may be noted in this connexion that, so far as seen, the present drainage-level, whether in the surface-streams or subterranean channels, is always below the soil-cap with foyaite boulders.

Several peculiarities of structure of the Tingua foyaites also point in the same direction, indicating a comparatively superficial origin. The type, as regards both mineralogical composition and structure, is extremely variable. Herr Graeff, in his excellent paper, has described a considerable number of varieties, all of which were collected in a small area, and might be duplicated, with many additions, at any point where the rock occurs. The four types of composition established by him on the bisilicate element (hornblende, biotite, augite, and ægerine) are difficult to distinguish in the field; and, from the mode of occurrence in loose blocks, the determination of their mutual relations is out of the question. So far as can be judged from a superficial examination, the more purely hornblendic type is most characteristic of the rocks of nearly uniform grain, the ægerine type of those that are most distinctly porphyritic. As regards structure, all possible gradations, from a normal granitic type of uniform or nearly uniform grain (always, however, with a porphyritic tendency) to a very pronounced porphyritic type, which only differs from phonolite in the coarser granulation of the elements of the groundmass, occur mingled in inextricable confusion.

An irregularity of structure roughly suggestive of stratification (*Schlieren* (?) structure) is beautifully brought out by atmospheric weathering. When exposed to water-action or embedded in the soil, the blocks of foyaite are rounded like a normal intrusive rock. Where exposed to the atmosphere on the hillsides, however, there is a very general tendency to become fluted, as represented in the cut on the next page (fig. 2). This peculiar style of weathering does not appear to be confined to any particular type of structure or composition; and on the worn or freshly-broken surface no appreciable

difference in texture, to which the unequal action of the atmosphere can be attributed, can be detected. The same feature is equally marked in many of the rocks of the Serra de Itatiaia, but has not been observed in those of Poços de Caldas and Cabo Frio, where, if it occurs, it is not sufficiently prominent to have attracted attention.

Fig. 2.



Fluted weathering of foyaite. From a photograph.

Included fragments of other rocks, or of different types of the same rock, are rare. The only one observed is a large angular piece of augite-syenite, of medium grain and rich in magnetite, which affects a linear arrangement, giving a gneissoid aspect to the rock *; but this has not been found in independent masses. Segregations of various kinds are extremely common. The most abundant and characteristic are confined to the porphyritic type of foyaite, and present the aspect of crystals or groups of crystals. An unusually perfect example, now preserved in the National Museum, is represented in fig. 3 on the next page. These are evidently of the same nature as the smaller polyhedral inclusions in the true phonolite, which have been discussed by Graeff and Hussak †, and determined by the latter as pseudo-crystals in the form of leucite. The accompanying figure (fig. 4), from a photograph, shows the mode of

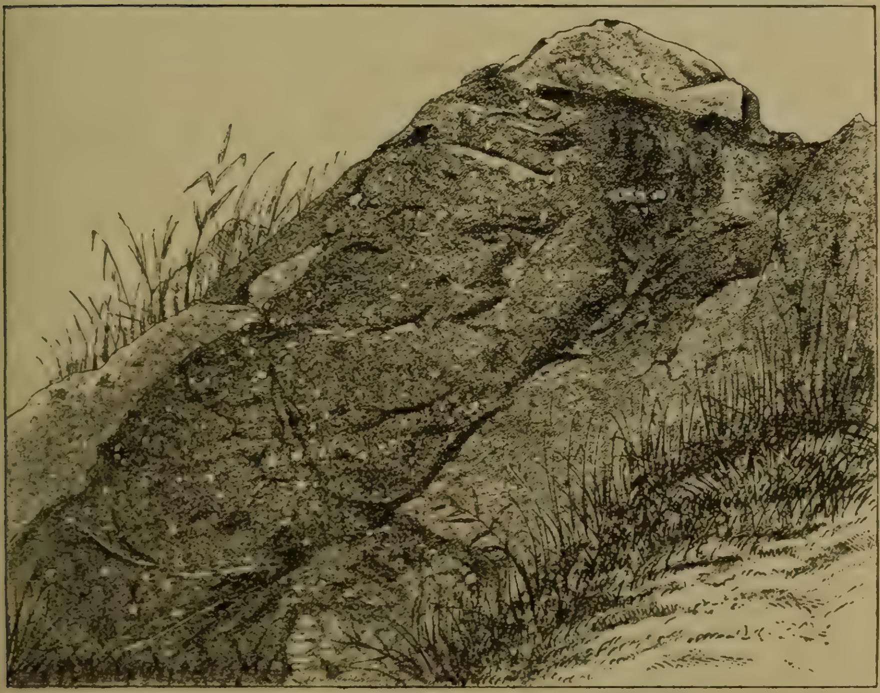
* This tendency to enrichment in magnetite is interesting, as at another locality (Ipanema, São Paulo) workable ore-bodies occur as segregations in dykes of a rock of this type.

† Neues Jahrb. 1887, vol. ii. p. 255, and 1890, vol. i. p. 166. The first-named author, who gives excellent detailed figures, considers them as inclusions of the foyaite, which is cut by the dyke and with which they are identical in structure and composition; the last named, having the advantage of much more favourable material, shows that they have the form of leucite, though *without a recognizable trace of that mineral*. The material placed in the hands of Dr. Hussak was obtained, after a diligent search for specimens, in just the proper stage of decay to cleave freely around the granular mass, so as to expose the outer face. Only one such could be found, which afforded several sharply-cut leucitohedrons of the form 202 (211) and angles of 131° and 146°.

Fig. 3.

Group of pseudo-crystals in foyaite, reduced 7 diameters.

Fig. 4.



Dyke of phonolite with pseudo-crystals in foyaite*.

* The foyaite to the left has been blasted away, exposing a part of the lateral face of the dyke in the upper part of the figure.

occurrence of these aggregations in phonolite. It represents a half-buried mass of foyaite near the eastern end of the Santo-Antonio aqueduct, traversed by a dyke of phonolite about a metre wide. Some specimens of similar rock are found abundantly at various points. Irregular holocrystalline aggregations, without definite form, also occur.

Large phenocrysts of orthoclase, augite, hornblende, titanite, and in one case of plagioclase (the only instance in which this mineral has been observed in the Tingua rocks besides certain pseudo-crystals) are frequently seen half-embedded in the pseudo-crystals, half in the surrounding phonolitic groundmass. Similar crystals form a part of the mass of the former, and in the case of the large aggregates in foyaite it seems to be the rule that an unusually large phenocryst of orthoclase has served as a nucleus *. The crystallization of the larger part of the mass, however, seems to have been coincident with that of the phonolitic groundmass, portions of which, as Dr. Hussak has observed, are sometimes included in the pseudo-crystals. While it is in general quite impossible to distinguish accurately between the elements of the first and second generation, it is probably quite safe to refer to the latter such parts as occupy the position which should, in a normal crystal, however rich in inclusions, be occupied by the leucite molecule. Such is the marginal layer, rarely absent, about a millimetre thick, composed of lancet-shaped orthoclase (with nepheline according to Herr Graeff), disposed normally to the faces of the pseudo-crystal. A lucky fracture revealed to Dr. Hussak a skeleton formation, of like composition and aspect, disposed in the interior of the mass according to the faces of the octahedron. A similar parallel (or radial) arrangement of lancet-shaped crystals is frequent throughout the mass of the pseudo-crystals, more particularly in the outer members of the large compound groups in the foyaite. From this it may be concluded that a large part of the mass of the pseudo-crystals (at least so far as the orthoclase and nepheline are concerned) are of a second generation, subsequent to the phenocrysts of the general mass of the rock, which probably tend to become concentrated in these centres of crystalline activity, and thus become embedded among the later-formed elements which complete the form of the aggregate.

A zonal structure is sometimes seen in the pseudo-crystals in the

* This is the case with a similar foyaitic aggregate, without crystalline boundaries, attached to the side of a large orthoclase in the phonolite of Fernando de Noronha, the only specimen of foyaite known from that locality (see Rosenbusch, 'Mikr. Phys. Gesteine,' pp. 91. 628; Williams, *op. cit.* p. 185). Large crystals of orthoclase project from the faces of the decomposed crystals from the Poços de Caldas locality, referred to analcime in my former paper (p. 470). I am now convinced that there are also pseudo-crystals in the form of leucite, which mineral has been found in fragments of phonolite from the same cutting. The only test applicable was that of crushing and washing the totally decomposed mass. The heavy residue obtained, consisting of altered fragments of titanite (?), was altogether too abundant to be regarded as inclusions in a *simple* crystalline mass. Undoubted pseudo-crystals, as perfect as those in the Tingua phonolite, occur in a porphyritic foyaite near the tunnel on the Caldas railway. A chance fracture revealed a portion of the outer surface of one of these masses showing three faces of the leucitohedron.

phonolite; it is usually quite distinct in the large simple masses of the foyaite, and in the central crystal of the compound groups, while it is wanting or less marked in the peripheral members of the same. These groups, as a whole, however, show zonal structure in the disposition of the peripheral pseudo-crystals in one or more rings around a central one, the interspaces being occupied by groundmass extraordinarily rich in basic elements (bisilicates, melanite, and magnetite). In one specimen of phonolite fluidal structure in the groundmass surrounding the pseudo-crystals was observed. Occasionally a block is found so crowded with these compound pseudo-crystals, standing out in relief through weathering, that the surface resembles that of a gigantic pineapple. Usually, however, they are rather distantly scattered, one or two only appearing in the space of a square metre. The simple crystals attain a diameter of 10–15 centimetres, which is more than doubled in the compound groups.

To account for the formation of these singular masses Dr. Hussak rejects, with good reason, the hypothesis that they are inclusions of pre-existent foyaite; and, arguing from their complicated structure against the hypothesis of pseudomorphism by alteration, he looks upon them as true pseudo-crystals, representing a tendency to the formation of leucite under physical conditions unfavourable to the complete development of that mineral. None of the sections, thus far examined, have shown unmistakable leucite either in the pseudo-crystals or the groundmass, although rarely decomposition-products are observed that may possibly represent it. That these aggregates are intratelluric is shown by the phonolite dyke at Tingua and the foyaite sheet at Poços de Caldas; while the fact that the leucite form, skeleton structure, &c. are given by a second generation of orthoclase and nepheline around an aggregate of phenocrysts, indicates their completion in the later stages of the consolidation of the magma, and consequently a comparatively superficial origin *.

Diecke has suggested that under increased pressure the formation of leucite is impossible †. It may be supposed that these aggregates have been formed in a magma that had come to rest under a pressure sufficiently reduced to allow of the tendency to the formation of leucite, but still too high to permit of its complete development, so that, after sketching out the form and internal structure of leucite, the material crystallized as orthoclase and nepheline. It is difficult, however, to conceive how a mere tendency, without the substance, could produce such perfect crystalline forms, and it may be suggested that perhaps crystals of leucite, exceedingly rich in inclusions (phenocrysts from the surrounding magma), were actually formed, but that, before the complete consolidation of the magma, some change of conditions brought about, through magnetic action, a pseudomorphosis of the leucite molecule into orthoclase and nepheline.

* The same conclusion is indicated by the sanidinite 'bombs' brought from Vesuvius by the late G. vom Rath, in which, according to Dr. Hussak, identical pseudo-crystals occur. I have been unable to find any reference to these bodies in the writings of Vom Rath at hand.

† Neues Jahrb. Beilage, vol. vi. p. 226.

Aside from the phonolites and foyaites discussed above, the other eruptive rocks, thus far known from Tingua, are of petrographical rather than geological interest. The tendency of certain of the phonolites towards a more highly felspathic type (trachyte) has already been noticed, as well as the occurrence of a small dyke of undoubted trachyte (p. 255). The principal geological interest of this occurrence arises from the fact that, at another point in the vicinity of Rio de Janeiro (Santa-Cruz branch of the Central Railway), the same rock is found in a number of large dykes in the immediate neighbourhood of a plexus of small dykes of phonolite and various types of basic rocks identical with those of Tingua. All of these occur in a spur from an elongated isolated mountain-mass, the Serra de Mendanha or Madureira, one extremity of which is only five or six miles distant from the Tingua peak; and they lead to the suspicion that this mass will be found to be very similar to that of Tingua in origin and composition. At the only point thus far examined, a considerable area of a very coarse-grained highly-felspathic rock was found. Such a type would be produced by the disappearance of nepheline from foyaite, and an examination of this mass will probably lead to the discovery of interesting relations between the foyaites and certain more highly-acid types of eruptives. An interesting occurrence in the Serra de Mendanha is that of a small partially-decomposed dyke of perlite.

The frequency of small dykes of basic eruptive rocks about the margin of the Tingua mass, and for a distance of several kilometres beyond it, has already been referred to. As yet nothing corresponding to the extensive bodies of basalt (leucitite) in the otherwise very similar eruptive mass of Poços de Caldas has been seen; but, on the other hand, these rocks are at that place so decomposed and concealed from view, that but for exceptional facilities (extensive railway-cuttings in the deeper portions of the mass), such as do not exist at Tingua, they would never have been discovered. All things considered, the occurrence in the upper part of the Rio do Ouro valley of large masses of some sort of basic rock is extremely probable. The dykes seen vary in thickness from 10 cm. to 1 m., and, with the exception of three found in the tufaceous phonolite, are in gneiss.

The rocks of these dykes vary considerably in mineral composition and aspect under the microscope, no two being exactly alike; but all present certain characters in common, which led Prof. Rosenbusch (to whom a considerable collection was submitted) to lump them all together as "a peculiar group of augitite" *. This view, based upon petrographic considerations, is in perfect accord with their geological occurrence, since not only at Tingua, but at three other localities, the various phases occur together, and in the immediate vicinity of eruptive centres characterized by nepheline rocks. Moreover, at one of these localities (near the Serra de Mendanha) basic aggregates, closely resembling certain rocks of this group, have been observed in phonolite. The fundamental type presents a colourless glass-basis with microliths of augite, generally accom-

* 'Mikr. Phys. Gesteine,' 2nd ed. p. 821.

panied by varying proportions of amphibole and biotite, and is thus a typical augitite. Olivine is almost always present, and, particularly at Tingua, often becomes so prominent as to produce a limburgite. The glass basis tends to become individualized as plagioclase and nepheline, giving a tephrite-like form, or as plagioclase alone—so that, in the extreme forms with almost complete disappearance of glass, a type is produced that by many would be called a felspar-basalt. This tendency to felspathic types is more pronounced at Tingua than at the other localities. All of these forms occur associated in such a way as to appear to be contemporaneous and modifications of the same original magma. The three dykes above mentioned, for example, all cut the tufaceous phonolite at intervals of a few metres only, and, while one is a typical augitite, another might be called a limburgite, and the third a felspar-basalt.

Discussion.

The Chairman (Mr. Hudleston) supposed, from the evidence, that the Tingua mass was a volcano, and that therefore it was not of very great age, as it had not been entirely denuded.

Mr. Bauerman was pleased to see the excellent way in which the Author was carefully working out the geology of the district he had described. He himself had visited the district, and was struck with the many features of great geological interest displayed therein.

Mr. Hulke was reminded of the rock of the Hirschenberg, in the Eifel, by the Author's descriptions. The Hirschenberg rock contains leucites, which were with difficulty recognizable, but in the cracks of the rocks were little groups of crystals with the crystalline faces preserved.

Prof. Green asked whether the foyaite masses might possibly be intrusive sheets.

The Author, in reply, stated that there was nothing between gneiss and Quaternary in the region. The only place where there was hope of getting a clue was at Poços de Caldas, described in his previous paper, where sedimentary rocks occur, containing eruptive rocks of the same nature as the supposed volcanic rocks, and cut by dykes of the same nature. Not very far away are Carboniferous fossils; the rocks containing them continue to near the foot of the mountain and agree with the Carboniferous rocks in character; moreover, no other sedimentary rocks are known in the whole region. All the nepheline-bearing rocks examined by the Author present the same characters, and look as though they might be contemporaneous. Cavities in rocks in the district have been found lined with analcime, but no leucite has been yet found in such cavities, though he had no doubt it would ultimately be found in the rocks. He had seen leucites from Arkansas having the same characters as those presented by the masses he had described, and noted that Dr. Hussak had referred to a similar structure from Monte Somma. He suggested in the paper that the foyaite-sheets were not absolutely superficial, but forced through the incoherent upper masses of a volcanic cone.

## 17. *The* Shap Granite, *and the* Associated Igneous *and* Metamorphic Rocks. By Alfred Harker, Esq., M.A., F.G.S., and J. E. Marr, Esq., M.A., Sec.G.S., Fellows of St. John's College, Cambridge. (Read February 4, 1891).

[Plates X., XI., & XII.]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### § I. Introduction.

Having been struck with the absence of any detailed description of the metamorphism caused by the intrusion of a granite mass into a complex group of volcanic products, we devoted ourselves to an examination of the alteration produced by the well-known intrusion of Shap Fell in Westmorland, being led thereto by a knowledge that the volcanic rocks themselves presented a considerable diversity of characters, and that we should be to a certain extent able to contrast the effects produced on the volcanic rocks with those shown by fairly normal sedimentary rocks of various kinds. Although the intrusive mass has been so frequently noticed, and the literature on the subject is somewhat extensive, very few authors have touched in detail upon the composition of the granite and on the metamorphism of the surrounding rocks. Indeed, the following papers are all to which we shall have to refer with any frequency, and which we therefore, to save trouble, cite at the outset:—

Prof. H. A. Nicholson, "On the Granite of Shap in Westmoreland." Trans. Edin. Geol. Soc. vol. i. (1868) p. 133.

J. Clifton Ward, "On the Granitic, Granitoid, and Associated Metamorphic Rocks of the Lake District.—Part II. On the Eskdale and Shap Granites, with their Associated Metamorphic Rocks." Quart. Journ. Geol. Soc. vol. xxxi. (1875) p. 590.

Professors Harkness and Nicholson, "On the Strata and their Fossil Contents between the Borrowdale Series of the North of England and the Coniston Flags." Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 461.

J. A. Phillips, "On Concretionary Patches and Fragments of other Rocks contained in Granite." Quart. Journ. Geol. Soc. vol. xxxvi. (1880) p. 1.

J. A. Phillips, "Additional Note on Certain Inclusions in Granites." Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 216.

J. J. H. Teall, "British Petrography" (1888), p. 322.
Messrs. Aveline, Hughes, and Strahan, Mem. Geol. Survey, "The Geology of the Country around Kendal, Sedbergh, Bowness, and Tebay," 2nd ed. (1888) p. 34.

The granite forms an irregular oval, having a longer diameter from E. to W. of a little under two miles, whilst its shorter diameter in a N. and S. direction is somewhat more than a mile, and the intrusion is situated very near to the boundary-line between the Ordovician and Silurian rocks, both of which are altered by it, and, as will be subsequently seen, its probable apophyses penetrate upwards into rocks of Lower Ludlow age. On the other hand, it was long ago pointed out that the porphyritic pink felspars of the granite occur as fragments in the basal conglomerate which underlies the Carboniferous Limestone. As they appear to be somewhat limited therein, we may mention that they are seen in vast profusion in a small cliff on the right bank of Wasdale Beck, a few yards S.W. of Shap Wells Hotel, and near to where the Carboniferous conglomerate rests upon the upturned edges of the Coniston Flags. The date of intrusion of the granite is therefore definitely fixed as taking place after the deposition of the Lower Ludlow rocks, and before that of the basal Carboniferous conglomerate, and it is usually assumed that the rock was intruded in post-Silurian but pre-Carboniferous times, as is indeed highly probable. The apophyses of the granite occur in a considerable abundance to the south, as seen on the Geol. Survey map, and there are a good number on the north side also. Besides this, there is a network of irregular veins and branches along the immediate margin, especially on the steep west face, which renders the determination of the actual boundary somewhat difficult, and indeed the linear boundary of the map must be taken as drawn through the points where the granite is not mixed up to any extent with portions of the rock through which it has broken*. The general shape of the intrusive mass will be discussed subsequently.

The metamorphism produced by the granite is stated in the Survey Memoir to extend to a distance of about a mile from the margin. This appears to be the case, though we find that the production of new materials is confined to a belt extending not more than $\frac{3}{4}$ mile from the contact.

It is necessary here to give some account of the trend, order of succession, and lithological characters of the various rocks which come within the influence of the granitic mass, and to describe a section showing the succession of such rocks where they put on their normal aspect away from the granite.

The principal lithological varieties of the rock are exhibited upon the map, but for our purpose a more minute subdivision than can be laid down upon a small map is necessary, and we therefore

* [We have corrected the northern boundary of the granite on our map by reference to the MS. six-inch map in the Geological Survey Office, to which the Director-General has kindly allowed us access.—March 11th, 1891.]

append the following table of succession of the rocks in descending order:—

| | |
|---|---|
| Bannisdale Slates. | |
| Coniston Grits. | |
| Coniston Flags, | Upper Coldwell Beds. |
| | Middle do. do. |
| | Lower do. do. |
| | Brathay Flags. |
| Stockdale Shales (missing). | |
| Ashgill Shales (missing). | |
| Coniston Limestone, | Upper Limestone. |
| | Calcareous Breccia. |
| | Rhyolite. |
| | Lower (Stile End) Limestone. |
| Upper part of "Borrowdale Series" of Harkness and Nicholson ............ | Rhyolitic Group. |
| | Andesitic Group. |

All of these are affected by the granite with the exception of the Bannisdale Slates, into which, however, apophyses of the granite are intruded.

It will be convenient if we append a short description of the general characters of the rocks, as seen in a fairly continuous section at no great distance from the granite, but nevertheless outside the zone of alteration, noticing at the same time any marked differences (not due to metamorphism) between the rocks in this section and those developed within the altered region.

Fortunately, an excellent section of the strata (fig. 1, p. 270) is shown in Stockdale, at a distance of less than four miles from the S.W. margin of the granite, and the strata can be traced more or less continuously from that valley to the margin of the granite, disposing of all doubts as to the identity of the different beds.

Commencing with the Silurian rocks, and omitting the Bannisdale Slates, we find the Coniston Grits in Long Sleddale, half a mile below Stockdale, in their normal form of fine-grained grauwacke grits, striking with the rest of the Silurian rocks of this tract in a general E.N.E.–W.S.W. direction. Below them are the Upper Coniston Flags (Upper Coldwell Beds), slightly gritty laminated flags of a bluish colour. The Middle Coldwell Beds differ from these in being calcareous, whilst the Lower Coldwell Beds are grits very similar in character to the beds of the Coniston Grits. All of these beds, except the latter, contain Ludlow fossils, and the Lower Coldwell grits probably mark the base of that series.

The Lower Coniston Flags (Brathay Flags), the equivalents of the Wenlock series, and containing the usual Wenlock graptolites, are blue laminated flags, less gritty than the beds of the Upper Flag division, but otherwise resembling them.

The Stockdale Shales, being faulted out in the zone of alteration, do not require description.

The Upper Limestone of the Coniston Limestone series is an impure limestone, containing much argillaceous matter, and interstratified with calcareous shales which contain a certain amount of fine ashy material. Its lower part is more calcareous than the

upper, but is by no means pure. At its base is a breccia, which is somewhat variable, consisting of a calcareous ashy matrix with rounded and angular fragments of rhyolite. The upper part of this breccia consists of a limestone with a few more or less rounded rhyolite fragments, whilst the base is to a large extent composed of rhyolitic detritus with comparatively little calcareous matter. This breccia is seen occupying precisely the same position at Yarlside Crag, again at a point $\frac{5}{6}$ mile W.S.W. of Wasdale Head Farm, immediately west of the farm itself, and in Blea Beck, at the Spa Well in the grounds of Shap Wells Hotel. Below this is a thin ash band, and then a thick rhyolite, nodular at the summit and fissile below. This is well known, being inserted on the Survey Map from Wasdale Head Farm to Stile End, on the west side of Long Sleddale, a total distance of over five miles, and it is the rock which is figured in Mr. Teall's "British Petrography," plate xxxviii., the specimen figured having been obtained from a point half a mile W. of Stockdale.

The Lower Limestone (Stile End Limestone) is less calcareous and more ashy than the upper one, and the calcareous matter is often collected into nodules.

The Rhyolitic Group below the Coniston Limestone, and forming here the summit of the Borrowdale series, consists of a succession of fine green rhyolitic ashes and breccias of no great coarseness, the latter containing rhyolitic fragments *. It will be eventually seen that farther to the west this group also contains rhyolite flows, and beds of a gritty character, which are not found in the present section, but fortunately their nature is readily recognizable even within the zone of alteration.

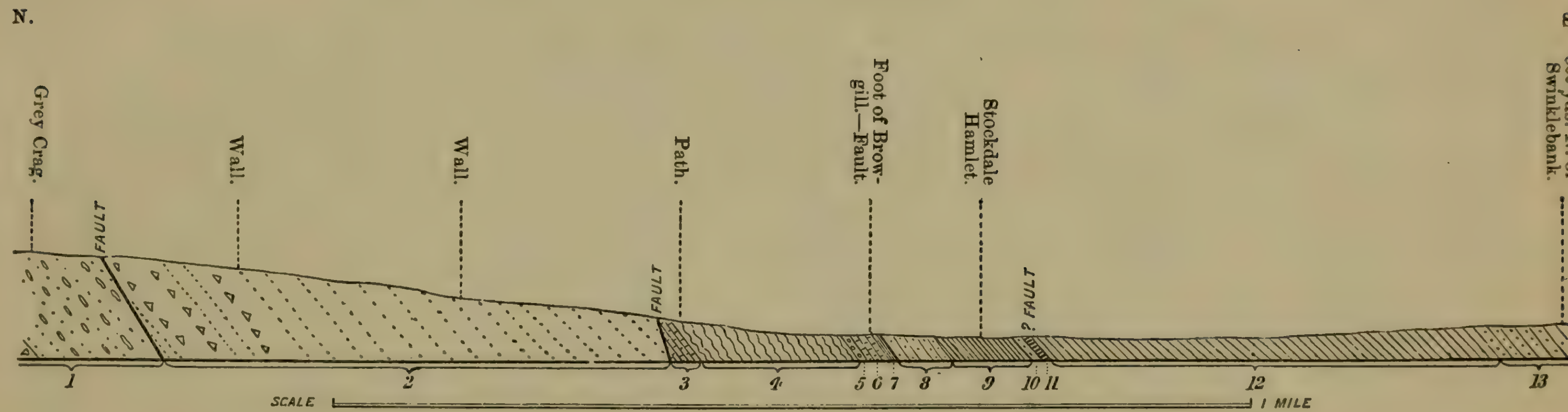
Lastly, below Grey Crag we meet with a group of vesicular andesites, interstratified with darker ashes, and with some breccias, the latter containing rhyolitic fragments, as is usually the case throughout the whole Borrowdale series whatsoever may be the nature of the associated lavas. These andesites have evidently undergone "weathering" at an early period, as their vesicles are now filled with calcite, chlorite, or both, and when the rocks have been subjected to cleavage, the vesicles have been flattened along the cleavage-planes.

In order to show the fairly constant character of the rocks above described, it will be convenient to give details of two other sections, one near the granite, and the other somewhat more remote, though still within the zone of alteration.

The section (fig. 2, p. 271) is taken obliquely across the strike of the beds (which has here curved round somewhat in a manner to be described in the sequel), being drawn from Demings Moss, about $\frac{1}{2}$ mile S. of the granite margin, to Wasdale Pike. The Coniston Grits are seen at Demings Moss, and the Upper Coldwell Beds extend from here to the summit of Packhouse Hill, in a somewhat

* In figs. 1–3, amongst the volcanic rocks, the wrinkled lines indicate rhyolite flows, the oval markings andesite flows, whilst rhyolitic and andesitic ashes are indicated by fine dots, and breccias by triangles.

Fig. 1.—*Section down Stockdale Beck, continued towards Swinklebank.*



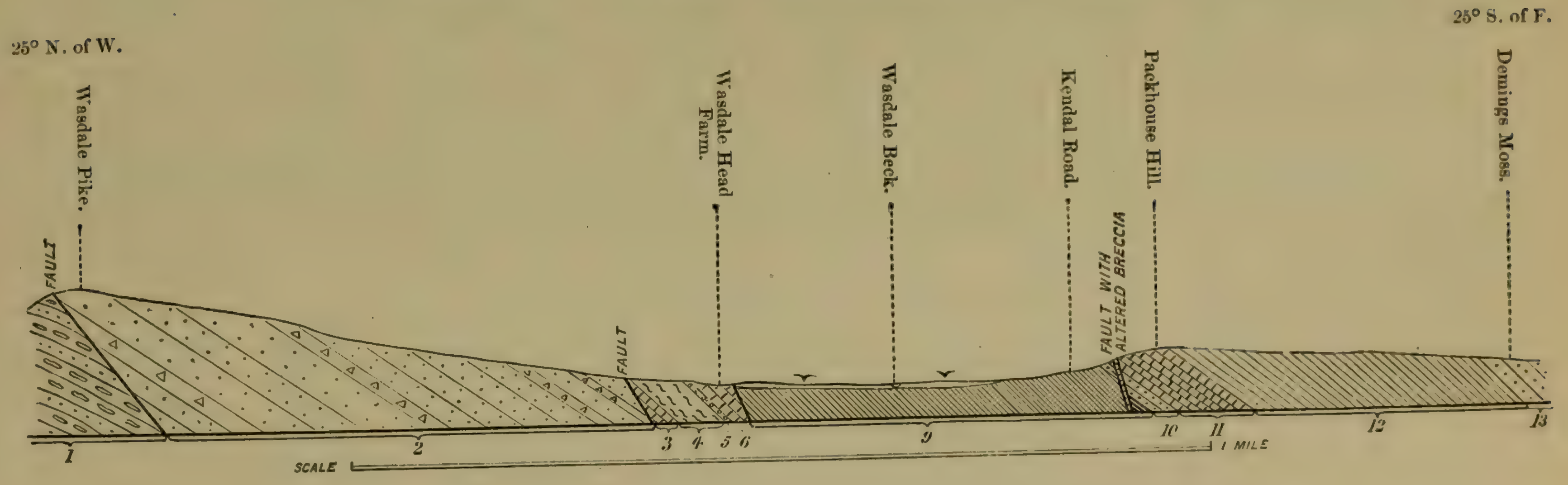

13. Coniston Grits.
12. Upper Coldwell Beds. ⎫
11. Middle Coldwell Beds. ⎬ Coniston Flags.
10. Lower Coldwell Beds. ⎪
9. Brathay Flags. ⎭

8. Browgill Beds. ⎫ Stockdale Shales.
7. Skellgill Beds. ⎭

6. Upper Coniston Limestone. ⎫
5. Calcareous Breccia. ⎬ Coniston Limestone series.
4. Rhyolite. ⎪
3. Lower Coniston (Stile End) Limestone. ⎭

2. Rhyolitic ashes and breccias. ⎫ Part of Borrowdale series.
1. Andesites, andesitic ashes, and breccias. ⎭

Fig. 2.—*Section from Wasdale Pike to Demings Moss, across the metamorphosed beds.*




13. Coniston Grits.
12. Upper Coldwell Beds. } Coniston Flags.
11. Middle Coldwell Beds.
10. Lower Coldwell Beds.
9. Brathay Flags.

6. Upper Coniston Limestone. } Coniston Limestone series.
5. Calcareous Breccia.
4. Rhyolite.
3. Lower Coniston (Stile End) Limestone.

2. Rhyolitic ashes and breccias. } Part of Borrowdale series.
1. Andesites, andesitic ashes, and breccias.

⤙ Alluvium.

"porcellanized" condition; they are lighter than in the unaltered state, and break with a conchoidal fracture, but the planes of lamination are clearly shown. The Middle Coldwell Beds occur as white or cream-coloured laminated porcellanous beds on the summit of Packhouse Hill, and immediately below them, above the road from Kendal to Shap, the Lower Coldwell Beds crop out as quartzite, though there is a fault between the Middle and Lower Coldwell Beds marked by a breccia composed of fragments of the two rocks, and itself altered by the granite. These are in turn underlain by the Brathay Flags, which strongly resemble the Upper Coldwell Beds in general appearance, though they have undergone greater alteration.

On the north side of Wasdale Beck the Upper Limestone band of the Coniston Limestone occurs in a small stream coming from the north, immediately west of Wasdale Head Farm. It is greatly altered but clearly recognizable, though changed into a white saccharoidal rock, for it has more finely-laminated beds interstratified with it, and at its base passes into the breccia with fragments of rhyolite seen weathering out on the exposed surfaces. Beneath this the rhyolite is readily recognizable, nodular at the summit, and fissile below, and underneath this comes the Lower Limestone, with the original calcareous patches occurring as white nodular masses embedded in a less pure rock. The presence of the Coniston Limestone at this point was recognized by Profs. Harkness and Nicholson so long ago as 1868 *.

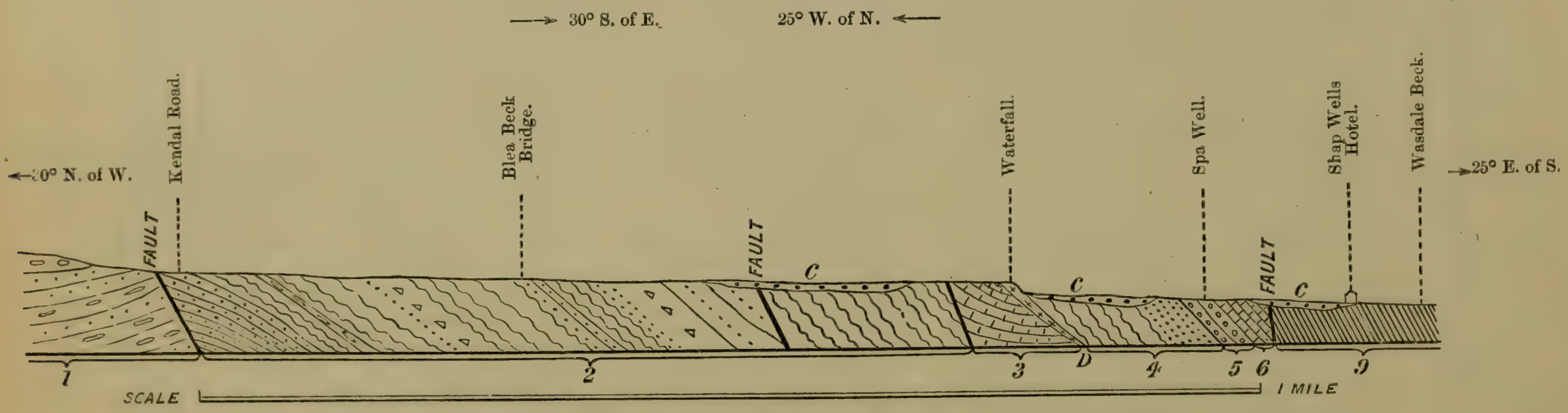
Ascending the hill from this point, a series of rhyolitic ashes and agglomerates in a state of considerable alteration is traversed until the summit of Wasdale Pike is reached, and immediately north of this the vesicular andesites and interbedded banded ashes crop out on the moorlands between this point and Sleddale Pike. We may here state that we assume the presence of vesicles to be sufficient evidence that the rocks in which they occur are true lavas and not ashes, as we cannot conceive the production of vesicles of this nature throughout the whole mass of a fragmental accumulation, and the microscope fully confirms our view. In this manner we are often enabled to distinguish between lavas and ashes even when the rocks have undergone great change near the contact with the granite.

The third section (fig. 3) is drawn from the Coniston Flags of Wasdale Beck, through the grounds of Shap Wells Hotel, in a direction generally parallel with the course of Blea Beck to the Andesitic Group west of the high road, on the southern flanks of Low Fell (Tewsett Pike).

The Brathay Flags are here hardened and splintery, and of a dark colour; they contain graptolites allied to *Monograptus vomerinus*. Between Wasdale Beck and the Spa Well in Blea Beck the lower rocks are covered by red conglomerate, but there is not sufficient room in the interval for the Stockdale Shales, the Ashgill

* Quart. Journ. Geol. Soc. vol. xxiv. p. 296.

Fig. 3.—*Section along Blea Beck from S. slope of Tewsett Pike to Shap Wells Hotel.*




*c.* Carboniferous Conglomerate.
D. Dyke.
9. Brathay Flags.—Part of Coniston Flags.

6. Upper Coniston Limestone.
5. Calcareous Breccia.
4. Rhyolite.
3. Lower Coniston (Stile End) Limestone.

} Coniston Limestone series.

2. Rhyolites, rhyolitic ashes, and breccias.
1. Andesites and andesitic ashes.

} Part of Borrowdale series.

Shales, and the higher portions of the Upper Limestone. The lower part of the latter at the Spa Well consists of 15 feet of nodular limestone, and banded limestones in calcareous shales, all somewhat hardened, but not greatly metamorphosed. It passes down into the breccia, which is very calcareous in its upper six feet, and crowded with small fragments of rhyolite, whilst the lower thirty feet consists of calcareous shales and grits with few rhyolite-fragments. The lower part of the breccia contains casts of *Lindstrœmia* and fragments of large trilobites in places, whilst a thin grit associated with it yields numerous *Tentaculites*. After a short interval, 10 feet of flaky rhyolitic ash is seen dipping down stream at a low angle, and then a break of many yards is occupied by the red conglomerate. At the top of the Hotel Plantation is a claret-coloured felsite with quartz crystals and tolerably large porphyritic felspars. Although this is in the position of the rhyolite between the two limestones in Stockdale and elsewhere, we have satisfied ourselves that it is intrusive. There is considerable disturbance at the junction between it and the underlying limestone, which is about sixty feet thick, and consists of calcareous bands and nodules interstratified with more shaly beds.

The top of the Rhyolitic Group is a nodular rhyolite, and, after another interval occupied by Carboniferous conglomerate, we meet with an alternation of more or less altered rhyolitic ashes, breccias, and lava flows, and one thin andesite, which extend up Blea Beck to the W. side of the high road, where they are faulted against the vesicular andesites and banded ashes of the south side of Tewsett Pike.

Hitherto we have merely considered the general succession of the beds without reference to their changes of strike and the faults by which they are affected, and it remains to say a few words concerning these.

The normal E.N.E.–W.S.W. strike of the Silurian strata and of the Coniston Limestone Group is slightly changed in the vicinity of the granite, curving round its southern margin. The Rhyolitic Group has its strike more strongly deflected, for the rocks turn somewhat sharply towards the S.E. on the western side of the granite, and appear to curve round with a mean N.E.–S.W. strike on the eastern side. The andesites dip at first in a southerly direction on the S.W. margin of the granite, though farther north they appear to turn over, and maintain a general northerly dip all along the northern margin of the granite; so that on the N.E. margin, the Andesitic Group is seen dipping away from the junction of the Andesitic and Rhyolitic Groups, as represented on the map. The absence of the Stockdale Shales indicates the existence of a strike-fault running between the Coniston Flag and Coniston Limestone series. This fault has been recently described by one of us, in a joint paper with Prof. Nicholson, as running across the district *.

* See Quart. Journ. Geol. Soc. vol. xliv. (1888) pp. 662 *et seqq.*

A second fault occurs at the base of the Stile End Limestone, as shown by its attenuation in Stockdale and its disappearance elsewhere; also by the change of strike in the Rhyolitic Group below the Stile End Limestone of Blea Beck.

Another fault separates the Rhyolitic Group from the Andesitic rocks to the north of it. The proof of this is furnished by the difference of dip of the two groups on the north-east margin of the granite, where the south limb of the anticline in the Andesitic Group is entirely cut out.

Besides these faults, others of minor importance cut through the Rhyolitic Group to the east of the granite. Their general position is shown on the map, though, owing to the quantity of drift which here covers the ground, we have not been able, in all cases, to indicate their exact position.

[As the existence of these minor faults does not directly bear upon the subject of this paper, we have not fully discussed the evidence for their general trend and hades. We hope to recur to this, however, in a future communication.—March 11th, 1891.]

## § II. Description of the Granite.

The well-known "Shap Granite" is familiar, not only as an ornamental building-stone, but also as the material of the famous boulders which have so often been made use of in tracing lines of glaciation in the north of England. The most striking feature of the rock is the occurrence of flesh-coloured crystals of felspar, one or two inches in length, in a matrix of moderately coarse texture and usually of greyish hue. In this matrix orthoclase, quartz, biotite, and a striated felspar may be detected by the unassisted eye or with a lens.

In strict accuracy the name "granite" is not quite applicable to the rock, which is differentiated from typical granitic rocks by its porphyritic character; but the name "granite-porphyry" has not been applied in this country except to rocks with a matrix of very fine texture, and it will be sufficient to designate the Shap Fell rock by its popular title, "porphyritic granite." We shall see, however, that its micro-structure also presents a departure from the rules which hold in most granitic rocks, the quartz being of anterior consolidation to the orthoclase.

The preponderance of felspars in the rock is partly explained by its chemical composition, the silica-percentage being rather low. Mr. E. J. Garwood, who has kindly made several analyses for us, finds 69·78, and Dr. J. B. Cohen, in another specimen, 68·55 per cent. of $SiO_2$. The rock is thus less acid than the Skiddaw and Eskdale granites, which yield 75·223 and 73·573 per cent. of silica respectively. Dr. Cohen's analysis is given on the next page (mean of two):—

| | I. | II. |
|---|---|---|
| $SiO_2$ | 68·55 | 68·54 |
| $Al_2O_3$ | 16·21 | 15·82 |
| $Fe_2O_3$ | 2·26 | 2·26 |
| FeO | not estimated | — |
| MnO | 0·45 | 0·52 |
| MgO | 1·04 | 0·93 |
| CaO | 2·40 | 1·99 |
| $Na_2O$ | 4·08 | 4·23 |
| $K_2O$ | 4·14 | 4·45 |
| $H_2O$ | not estimated | not estimated |
| | 99·13 | 98·74 |

I. Shap-Fell granite, bulk-analysis from an average specimen weighing 10 lb.; anal. J. B. Cohen.

II. Calculated composition obtained from the analyses of the porphyritic felspars and the groundmass given below (p. 278), on the supposition of one part of porphyritic crystals to nine of groundmass.

The specific gravity of a specimen of the "light" Shap granite was found to be 2·687.

The microscope reveals several minerals in addition to those enumerated above *.

Apatite is present in all the slides examined. It occurs in little prisms with hexagonal cross-section, and sometimes in very slender needles.

Zircon, in small quantity, is also a constant constituent, forming small prisms terminated by an obtuse pyramid. These two minerals are always the earliest products of consolidation, and contain no inclusions.

Magnetite is usually present, in little octahedra, in clusters of partly-developed crystals, or in less regular patches. The bulk of the mineral has separated at an early stage, but sometimes a portion is seen to mould the mica and later minerals.

Sphene is always present and often abundant. It commonly shows good crystal forms; namely, $n$ (123), $c$ (001), and $y$ (101), in Miller's notation; but twinning is not met with. The cleavage-traces are often apparent, making acute angles with the bounding lines of the section. The colour in thin sections is light to moderately deep brown, with well-marked pleochroism. Longitudinal sections show the three forms mentioned, $n$ being the best-developed; one of the axes of elasticity ($\alpha$) is nearly parallel to the length of such a section, and vibrations in this direction give a pale straw colour, in the perpendicular direction a light reddish brown. Transverse sections are parallelograms bounded by $n$-faces only, and show a deeper colour than the others, with slightly less dichroism. The absorption formula is—

$$\gamma > \beta > \alpha.$$

* The specimens illustrating this paper, with about 150 slides, are in the Woodwardian Museum at Cambridge. The figures given in square brackets refer to the numbers of the slides.

Looking at Lane's * two types of rock-forming sphene, it appears that this corresponds to the type which he associates with rocks poor in alkalies and rich in magnesia and iron-oxides. The sphene in our rock is free from inclusions, excepting occasional crystals of zircon and magnetite. The mineral sometimes occurs in granular patches, but there is no reason to doubt that these also are of original formation.

Dark mica is the only ferro-magnesian silicate proper to the rock. It forms moderately small flakes, which almost always, when well bounded, show the pseudo-hexagonal appearance with large basal plane. In connexion with certain marginal modifications of the rock, however, there occur larger plates of mica with a different habit. These have the shape of long narrow blades, bounded apparently by the forms *c* (001) and *b* (010), with irregular terminations. They are often as much as an inch long, with a breadth of less than $\frac{1}{10}$ inch. When fresh, the mica is of a deep brown colour with intense pleochroism, vibrations perpendicular to the $a$-axis (*i. e.* nearly parallel to the cleavage-traces in a section) being absorbed almost to opaqueness. The bisectrix is not quite perpendicular to the basal plane, as may be verified by a slightly oblique extinction in sections. This also enables us to detect in some crystals a lamellar twinning parallel to the base.

The mica encloses occasionally any of the previously-named constituents, besides its own secondary products. Its most usual mode of alteration, exhibited in almost all the slides, results in a partial decoloration, or more frequently a green colour in place of the brown, and a considerable diminution in the absorption and pleochroism. The process is effected along the cleavage-planes of the mica, and often gives rise to irregular lamellæ of green colour alternating with the brown †. A separation of granular magnetite invariably accompanies this mode of decomposition. Side by side with flakes so affected there are often others converted in their interior into a reddish-brown substance free from magnetite. This shows less intense pleochroism than the fresh mica, the absorption being rather less parallel to the $\beta$ and $\gamma$ axes, and greater parallel to $a$. The optical properties are retained so far as to show the lamellar twinning between crossed nicols, but the cleavage is obliterated. Probably this represents a further stage of change than the green mineral, the secondary magnetite having been reabsorbed in the form of ferric oxide. The marginal parts of the flakes so affected are usually green, and still show cleavage-traces in the sections. An examination of some basal sections of mica in the slides, or, better, of thin films carefully flaked off from the mineral, frequently reveals numerous minute needles of rutile disposed in three directions parallel to the boundaries of the hexagon. These we have met with only in the decomposing mica, and they may possibly be secondary

* Tscherm. Min. u. Petr. Mitth. (N.S.) vol. ix. (1888) p. 207.

† See Teall's 'British Petrography' (1888), pl. xxxv. fig. 1.

products rather than original inclusions *. They are well seen in the blade-like micas already referred to.

Mr. J. A. Phillips mentioned hornblende as a constituent of the Shap granite, but it is not found in any of our numerous specimens and slices.

The felspars of our rock fall under three heads: the earlier orthoclase, the plagioclase, and the later orthoclase. The first builds the large red crystals which give to the rock its porphyritic appearance. The crystals show the common habit, and are usually twinned on the Carlsbad law. The mineral is clearly monoclinic. Mr. Phillips speaks of it in one place as "microcline," but as the specimens alluded to formed part of the façade of a building, it is clear that they could not have been subjected to any decisive test. These large felspars enclose crystals of apatite and sphene, besides occasional flakes of mica and prisms of striated plagioclase. More rarely they contain little patches of quartz, or even a well-bounded crystal of that mineral [395]. Sometimes, however, we find numerous round grains of quartz enclosed in the marginal portion of the felspar crystals [796]. The inference is that these porphyritic crystals were formed at a time when the accessory constituents of the rock had already separated out, and the mica and plagioclase had begun to form, and that their growth only occasionally continued into the stage at which free silica began to separate.

For the following analysis (I.) of the porphyritic felspars we are indebted to the kindness of Dr. J. B. Cohen. The figures are the mean of two determinations :—

| | I. | II. | III. |
|---|---|---|---|
| $SiO_2$ .... | 65·41 | 64·48 | 68·89 |
| $Al_2O_3$ .... | 18·97 | 19·04 | 15·48 |
| $Fe_2O_3$ .... | .. | .. | 2·46 |
| FeO .... | 0·51 | .. | traces |
| MnO .... | traces | .. | 0·58 |
| MgO .... | 0·01 | 1·02 | 1·04 |
| CaO .... | 0·73 | .. | 2·13 |
| $Na_2O$ .... | 2·15 | 2·64 | 4·69 |
| $K_2O$ .... | 11·23 | 10·74 | 3·70 |
| $H_2O$ .... | not estim. | 0·78 (ign.) | not estim. |
| | 99·01 | 98·70 | 98·97 |

I. Porphyritic pink felspar of the Shap Fell granite: anal. J. B. Cohen.

II. Dominant felspar of the granite of Glenmalure, Co. Wicklow: anal. Galbraith; *cit.* Haughton, Quart. Journ. Geol. Soc. vol. xii. (1856) p. 173.

III. Groundmass of the Shap Fell granite: anal. J. B. Cohen.

The percentage of soda is worthy of notice; a small part of it is

* Rosenbusch, 'Mikr. Physiogr. d. petr. wichtig. Miner.' 2nd ed. (1885) p. 303. See also W. Maynard Hutchings, Geol. Mag. (1890) p. 264.

probably due to enclosed crystals of plagioclase; but, making liberal allowance for this, the potash- and soda-felspar molecules must be combined in the mineral in some such ratio as 4 : 1. The felspar resembles the dominant one in the granites of Leinster, investigated by Dr. S. Haughton, and the analysis of one of these is here quoted for comparison (II.).

Dr. Cohen has also analysed the groundmass of the granite: that is, the rock excluding the porphyritic felspars. From his figures (III.), and remembering that part of the potash must be contained in the mica, we see that among the smaller felspars of the rock plagioclase is the dominant variety. Comparing the figures in columns I. and III. with the bulk-analysis of the rock given above (p. 276), it is seen that the porphyritic crystals constitute about one-tenth of the whole mass of the rock (see column II. on p. 276).

The plagioclase felspar occurs in idiomorphic crystals, often enclosing zircon, dark mica, &c., but moulded by the quartz and later orthoclase; these facts sufficiently fix the time of formation of the mineral. Albite-twinning is always seen, the lamellæ being rather narrow. Carlsbad-twinning sometimes occurs in addition [395 *a*], and more rarely a lamellation answering to the pericline law [395, 876]. The optical properties point to oligoclase. The crystals are frequently turbid, being filled with a fine dust doubtless due to decomposition, and calcite is also to be detected, besides minute fan-like groups of fibres, probably of some soda-zeolite.

The quartz and later orthoclase call for no special remarks. The last-named mineral, being commonly the latest product of consolidation, is for the most part without crystal boundaries, and moulds the irregularly shaped or rounded grains of quartz (see Pl. XI. fig. 1). Micropegmatitic intergrowth of the two is not found in the normal type of granite.

The structure of the Shap Fell granite seems to warrant some inferences as to the conditions under which it was injected into its present position. The intrusion must have occurred soon after the close of the Silurian period. Taking the thickness of the Silurian strata as 14,000 feet, we obtain an approximation to the depth at which consolidation took place. By the consolidation of an igneous rock we must understand the consolidation of such of its constituents as crystallized *in situ*, and in particular of the one last formed, which in this case is the later generation of orthoclase. Earlier-formed minerals may have separated out from the magma at greater depths and been carried up to their present position. From a study of the fluid-cavities enclosed in the quartz of this rock, Mr. Clifton Ward deduced that it was formed under a pressure equivalent to the weight of 46,000 feet of strata, instead of the 14,000 which formed its actual cover; but this conclusion, as has been said, must be applied to the mineral, not the rock. It is improbable that the overlying strata would be able thus to withstand an upward pressure equal to more than three times their weight. Mr. Ward shows that, as regards this wide discrepancy, the Shap Fell rock is exceptional among the Lake District granites; but he fails to notice that it is

also exceptional in that its quartz crystallized prior to the final consolidation of the rock. If we suppose this mineral to have been brought up by the magma from its place of consolidation at a greater depth, the difficulty vanishes.

One of the most striking characters of the Shap Fell granite is the occurrence of distinct patches of darker colour and somewhat finer texture than the surrounding rock. These patches are abundant in the quarries, and may be well studied in the polished slabs and pillars used in building *. They are of rounded outline, though not usually spheroidal, and have a sharply defined boundary. Most of them are only a few inches to a foot or two feet in diameter, but there is one large enough to be separately quarried for setts. They contain, though rather more sparsely, porphyritic felspars like those of the normal granite; and Mr. Phillips gives instances of felspars lying partly in the dark patches and partly in the surrounding rock. The large felspars within the inclusions frequently have, however, a rather rounded outline, and present other peculiarities which will be described below.

It is evident that these phenomena cannot be explained by supposing the liquid granite to have caught up fragments of rocks broken through in its irruption and metamorphosed them to a crystalline condition. There are, indeed, some inclusions in the granite which represent highly altered fragments, but they are much less common than the type under consideration. They show a closer texture, and never enclose porphyritic felspars. Further, their form is quite irregular, and usually angular, and one large specimen in the Woodwardian Museum has evidently been a shaly or slaty rock, which has been partly split and penetrated by tongues of granite in the direction of its laminæ.

Leaving out of account evident included fragments, we have a type of inclusion possessing very definite characters, and agreeing with what is observed in many other granites, granophyres, and syenites. The inclusions are constantly of finer texture, greater density, darker colour, and more basic composition than their matrix. In the following table of silica-percentages the figures for the Shap Fell rock are obtained from Mr. Garwood, those for the other granites being quoted from Mr. J. A. Phillips's paper:—

| | Matrix. | Inclusion. |
|---|---|---|
| Gready, Cornwall ........ | 69·64 | 65·01 |
| Peterhead................ | 73·70 | 64·39 |
| Ardshiel (Fort William) .... | — | 52·43 |
| Shap Fell ................ | 69·78 | 56·95 |

It will be seen that the difference between matrix and inclusion is greater in the Shap Fell granite than in those of Gready and Peterhead.

An average specimen of an inclusion from the Shap quarries was found to have a specific gravity of 2·769. This is considerably

* *E.g.* at the Midland Grand Hotel, St. Pancras Railway Terminus.

higher than the sp. gr. of the normal granite, and the difference is greater than in Mr. Phillips's rocks *.

| | Matrix. | Inclusion. |
|---|---|---|
| Gready ................ | 2·72 | 2·73 |
| Peterhead .............. | 2·69 | 2·73 |
| Ardshiel (Fort William) .. | — | 2·93 |
| Shap Fell .............. | 2·687 | 2·769 |

It is interesting to compare the dark patches in the Shap Fell rock with those described by Dr. Ch. Barrois † in the intrusions near Rostrenen in Britanny. This, too, is a biotite-granite with large porphyritic crystals of orthoclase, which, however, are not red but white. In it occur patches of darker colour than the normal type, containing less orthoclase in the groundmass, more plagioclase, and that of a more basic variety, and more apatite. In these patches, however, the porphyritic crystals of orthoclase are wanting. This seems to be explained by the fact that these crystals, unlike those of the Shap rock, are of rather late consolidation, being posterior to the mica. In the Rostrenen rock, too, the patches are described as graduating into the normal rock, which would seem to indicate a greater degree of fluidity at the time of injection than in the case of the Shap granite.

Microscopic examination shows that these dark patches differ in some respects from the normal granite of the quarries, in both the relative proportions and the arrangement of the constituent minerals (see Pl. XI. fig. 2).

Apatite occurs rather plentifully, though locally, in small clear needles.

Zircon is less abundant, but a few crystals occur, chiefly in the mica.

Magnetite is present rather sparingly in little crystals and grains, as in the normal granite.

Sphene and dark mica occur in much greater abundance than in the typical Shap granite, and it is the latter mineral which gives the prevailing dark colour to the patches in question. It is mostly in rather small flakes, and shows much of the green decomposition-product noticed above. The sphene is sometimes almost as plentiful as the mica; it forms acute-angled crystals, as already described, or rounded grains, with deep brown colour and strong pleochroism.

The felspars here are almost constantly idiomorphic, and besides the porphyritic orthoclase, to be separately noticed, occur in larger and smaller crystals. Among these the triclinic felspar predominates over the monoclinic, and is more abundant than in the normal

* Among foreign rocks, the biotite-granite of the Barr-Andlau district in the Vosges compares very closely with that of Shap Fells. The figures given by Rosenbusch ('Steiger Schiefer,' pp. 147, 154, ed. 1877) are:—

| | Matrix. | Inclusion. |
|---|---|---|
| Silica-percentage ......... | 68·967 | 57·894 |
| Specific gravity ......... | 2·680 | 2·779 |

† Ann. Soc. Géol. du Nord, vol. xii. (1885) p. 6.

granite; it shows Carlsbad twinning, as well as fine lamellation on the albite-law. The orthoclase is in Carlsbad twins or simple crystals. Both felspars in the larger crystals exhibit zones of growth with slight variations of optical characters.

The quartz, which in the normal granite is of anterior consolidation to the orthoclase, has here been in general the latest mineral to form, and occurs interstitially in wedges, or often in granular patches. More rarely there is a micropegmatitic intergrowth of this mineral with part of the orthoclase [1046]. Again it is not uncommon to find isolated round grains of quartz, $\frac{1}{10}$ to $\frac{1}{4}$ inch in diameter, with no inclusions except an occasional grain of sphene; these must belong to a rather early stage of the consolidation [984, 1068–1070].

The porphyritic crystals of flesh-coloured orthoclase which occur within the dark patches are essentially identical with those in the normal granite, and must belong to a rather early stage of consolidation; but they present certain peculiarities which suggest that they have been subjected to chemical corrosion by the surrounding magma. They show very generally a somewhat rounded outline, and frequently have a well-marked narrow border distinguished by a white colour. Under the microscope it is seen that this border does not consist of orthoclase, but for the most part of plagioclase and quartz. The former is partly in lath-shaped forms, partly more irregular, and is moulded by the quartz. All the plagioclase crystals around any one orthoclase have a common orientation, presenting the usual crystallographic relation towards the monoclinic felspar, even when they have no point of contact with it. This fact, together with the rounded outlines of the central crystal and of the whole aggregate, point to the effects of corrosive alteration rather than an original intergrowth. It may also be observed that the border contains no inclusions other than those found in the orthoclase itself, as it would probably do if it were an actual addition of later date.

A singular modification of the granite is seen in a large loose block to the south-east of the intrusion and just below the footpath that runs along the north side of Wasdale Beck. Unfortunately we have not found this type *in situ*. Here, on a cursory examination, we seem to have something very like a gradual passage from the granite to a metamorphosed rock, or at least a contact of a very intimate character, the two rocks dovetailing into one another in a manner which makes it difficult to draw any definite line of demarcation between them. It seems as if little parallel veins of a pink felspathic rock proceeded from the granite penetrating the darker metamorphosed rock. In, or on the line of, these veins are large flesh-coloured felspars identical with those of the normal Shap granite; but the veins are sometimes too narrow to completely enclose these crystals, and the felspars also occur in the line of the veins beyond the point where these can be traced. The whole presents a striking resemblance to a section given by Dr. Ch. Barrois*

* Ann. Soc. Géol. du Nord, vol. xii. (1885) p. 15.

to show the dying-out of apophyses of the porphyritic granite of Rostrenen, which seems to have many analogies with the Shap Fell rock.

Any ideas based on the general appearance of this rock are, however, dispelled by a closer scrutiny, which proves that the whole is granite, and the semblance of a contact quite illusory. The granite differs somewhat from the normal type, especially in possessing a general "parallel structure." This parallelism is shown not only in the banding of the rock and the imitation of intrusive tongues, but also in the orientation of the large felspars and their restriction, for the most part, to particular lines. The pinkish colour of the rock along these lines must be referred to subsequent chemical action, as in the case of the pink granite in the quarries; and it here follows fine cracks which have probably served as channels for infiltration.

Slides of the rock [1071, 1280, 1281] show some curious characters. There is a distinct banded structure on a small scale. In some bands quartz is abundant, and then tends to be idiomorphic towards the felspar as in the normal granite: in other bands felspar is far in excess of quartz, and is then moulded by it, as in the dark patches in the quarries described above. Another link with these dark patches is the abundance of magnetite and apatite, but we have not identified any sphene. The rock, moreover, has peculiarities not found in either the normal granite or the dark patches. The magnetite, mainly occurring in streaks parallel to the banding, shows some crystal forms, but in some cases moulds the felspar. The brown mica is partly of early consolidation, but partly posterior to the felspars. Much of this mineral shows green coloration or bleaching, and finally conversion into a yellowish-brown substance with complete loss of the original structure.

The most striking feature, however, is the abundant occurrence of andalusite in idiomorphic, though rather rounded, prismatic crystals, usually coated with little flakes of yellowish or greenish-brown mica (see Pl. XI. fig. 3). The andalusite is usually clear and colourless, only occasionally showing the characteristic pleochroism:

$\alpha$ ($c$), pale rose-pink; $\beta$ and $\gamma$, colourless or very faint green.

The inclusions are of magnetite, zircon, and mica, and around some of these, especially the zircon, the well-known pleochroic halo* is well seen, the colours being:

$\alpha$ ($c$), bright yellow; $\beta$ and $\gamma$, colourless.

Andalusite as a regular constituent of granite has been recorded by Mr. Teall † and Dr. E. Cohen ‡ of Greifswald. As an accessory in granitic dykes it is also recorded in Spain §, Cornwall, and

* Rosenbusch, 'Mikr. Physiogr. d. petr. wichtig. Miner.' 2nd ed. (1885) p. 380.
† Min. Mag. vol. vii. (1887) p. 161.
‡ Neues Jahrb. (1887) vol. ii. p. 178.
§ Macpherson, Ann. Soc. Esp. Hist. Nat. vol. viii. (1879) p. 229.

Alsace*, while Von Gümbel† mentions it as occurring in pegmatite-veins in Bavaria.

In connexion with the parallel structure in this rock, it may be observed that at one place in the quarries the granite has a banded appearance not unlike some gneisses, a phenomenon doubtless due to a certain fluxional movement of the mass. In the general bulk of the granite the only indication of flow is an occasional rude parallelism of the long axes of the porphyritic felspars.

It remains to allude to some other special mineralogical and textural modifications exhibited in certain parts of the granite mass. It may be noticed that two varieties of the rock are recognized for building purposes, the difference being one of colour only. In both the large porphyritic felspars are of a flesh-red tint, but in the most common type the other felspars of the rock are white, while in the "dark" variety they too are red. The relations of the two rocks as seen in the quarry suggest that the latter is a modification of the former, produced by secondary actions, and connected with infiltration along fissures. This is certainly the case with some other granites, which are red in the neighbourhood of joint-surfaces, but grey in the interior. In one place in the Shap Fell quarry, extensive weathering along a main divisional plane, assisted perhaps by some degree of sliding, has converted the granite for some distance into a soft, greenish, earthy material.

The ordinary granite is in some places distinctly cut by small veins of a lighter coloured and somewhat finer-grained granite without porphyritic crystals. Although thus clearly posterior to the main intrusion, these may reasonably be referred to the same general source.

The texture of the normal granite itself seems to be very constant throughout the mass of the intrusion. It does not become finer in the marginal parts, nor, usually, in the nearest offshoots connected with it, so far as our observation goes; but the large porphyritic crystals are wanting in the small ramifying veins on the border of the mass, as if the narrowness of the fissures, though these are wide enough to contain the felspars, had offered some impediment to their floating in.

On the other hand there are, in one or two places at least, marginal modifications of the granite, which present a coarser texture than the normal type, as well as some mineralogical differences. This is seen on the hillside above Wasdale Head, about 350 yards N.W. of the farm. Here, at the contact with the metamorphosed rocks, the granite consists almost entirely of large crystals of pink felspar, with very little quartz, and the flakes of dark mica have the long blade-like habit already mentioned. Mica also occurs at the same place in the form of thin films adherent upon the crystal-faces of the felspar, which is partly idiomorphic. Again, the junction of the granite with metamorphosed ashes (altered to the appearance of mica-schist) is exposed in the tramway-cutting at the north-east

* Rosenbusch, 'Mikr. Physiogr. d. massig. Gest.' (1887) p. 31.
† Geogn. Beschr. Königr. Bayern, vol. ii. p. 317.

corner of the granite mass. Here a narrow band in the granite consists mainly of pink felspar, but has some quartz intergrown with it as a rude pegmatite [794–796]. There is also mica with the blade-like habit, as in the other case. The pegmatite band does not border the granite, but runs horizontally at right angles to the vertical face of junction.

A remarkable section is seen on the west side of Sherry Gill. Here the granite is seen underlying the altered rocks with a low angle of dip, and is probably a large sill rather than the main mass of the intrusion. Along the junction runs what at first sight appears to be a quartz-vein; but on examination it is found that the vein must have been a rather coarse-grained aggregate of felspar and quartz ("pegmatite" of some writers), in which the felspar has been largely replaced by quartz. The former mineral had often crystal outlines, and the process of replacement, which began in the interior of the crystal, is seen in various stages. A similar vein cuts through this, as well as through the granite and the metamorphosed rock, proving that veins of this kind were not all produced simultaneously.

As a somewhat analogous phenomenon may be mentioned a large cavity seen in the heart of the granite-quarries. It occurs in connexion with a joint, the surface of which is laid bare, and it has a width of about six inches from the joint-surface. This is lined with large felspars and quartz showing crystal faces, while around it is a narrow margin of pegmatite with graphic structure.

The geodes frequently contain well terminated crystals, and, in addition to the minerals mentioned, we have noticed in these and the joints talc, calcite, fluorite, malachite, iron pyrites, copper pyrites, molybdenite, and mispickel (?).

The replacement of the felspars by quartz at Sherry Gill, presumably an operation involving the agency of water, must belong to a late stage in the history of the intrusion. Perhaps we may assign to the same period the production of white mica along joint-faces in the metamorphosed rocks, accompanied by modifications extending to a very short distance from those planes. They have been observed in the Andesitic Group near Wasdale Pike, in the limestones of Wasdale Head Farm, and in the Coniston Flags of Wasdale Beck. Mr. E. H. Acton has kindly examined spectroscopically the mica from the last locality, and finds in it no trace of lithia; it is apparently an ordinary potash-mica.

## § III. The Dykes and Sills and their Relations to the Granite.

An interesting group of intrusions is well exhibited in a valley about a mile south of Shap Wells Hotel at Stakeley Folds and Gill Farm. Stakeley Folds is two thirds of a mile from the nearest granite outcrop. Here, and within three or four hundred yards to the south-east, four distinct sills are seen, injected one above the other at slightly different horizons in the Coniston Grits.

The highest sill, which, owing to the dip, is the lowest down the valley, shows a grey compact ground, studded with little quartz-grains and flakes of dark mica, and enclosing porphyritic felspars, some of which are one or two inches long. The quartz grains are mostly rounded, but occasionally a bipyramidal crystal is seen. The most conspicuous feature of the rock is the occurrence of felspars of flesh-red colour, some with Carlsbad twinning, which at once recall those of the Shap Fell granite, but have the rounded outlines and often the well-marked borders associated especially with the dark inclusions in that rock. Besides the above minerals, the thin slices cut from this sill [1157, 1158] contain apatite prisms, occasional zircons, and abundant acute-angled crystals of brown pleochroic sphene, like those so characteristic of our granitic inclusions. When the zircon is enclosed by mica, it is surrounded by an intensely absorbent pleochroic halo—a character which we have noted in the Shap Fell granite itself, and which is well known in many others. The mica is of the usual brown colour. Its mode of alteration is sometimes like that of the mica in the granite; while sometimes it gives rise to the interposition of lenticles and streaks of calcite along the cleavage-lamellæ in the fashion usually seen in lamprophyric rocks. The rounded grains of clear quartz have inlets and enclosures of the groundmass, which is that of an ordinary quartz-porphyry, in which, however, part of the felspar has separated out in little prisms. The porphyritic felspars enclose a few mica-flakes, as well as the earlier accessories. Both orthoclase and oligoclase are represented. The latter sometimes occurs in clusters of small crystals, with irregular junction with one another, but presenting crystal forms to the surrounding groundmass. Mr. Teall *, in describing similar clusters of felspar crystals in the Tynemouth dyke, has pointed out that this accords with the view that such crystals were formed under plutonic conditions, and floated up in the magma into their present position.

The next sill has, to the eye, a similar grey ground, with perhaps rather more mica, and encloses little plagioclase crystals and scattered grains of quartz about $\frac{1}{10}$ inch in diameter, but apparently none of the large red felspars. The microscopic characters accord with those of the former rock, except that there is very little sphene present [1159].

The preceding rocks may be called micaceous quartz-porphyries. The next sill has in the field a dull brown ground crowded with flakes of brown mica, and would naturally be mapped as a mica-trap. It contains, however, large red felspars with rounded outline, and a few scattered blebs of quartz. The microscope shows that these felspars are of a striated variety, probably near oligoclase, with a narrow border of orthoclase [1160]. The interior of each crystal is twinned according to the albite and Carlsbad laws, and the Carlsbad twinning is continued into the border of orthoclase. The slide contains abundant brown mica, which has suffered alteration chiefly of the kind producing calcite: there is but little mag-

* Geol. Mag. (1889) p. 481.

netite, either original or secondary. The groundmass of felspar and quartz is too far decomposed for minute examination, but it is clear that the rock has been of a much more acid type than such mica-traps as those found, for instance, in the Sedbergh district.

The lowest and thickest sill, at Stakeley Folds itself, consists of a quartz-porphyry in which the porphyritic elements are much more crowded than in the foregoing, forming a considerable proportion of the mass. The quartz grains are rounded, but with occasional idiomorphic faces, and the felspars comprise both orthoclase and oligoclase. The slice shows plenty of brown mica, altered into the green mineral along cleavage-planes [1161].

Two sills are seen near Gill Farm, farther down the same valley. The lower of these two is a red quartz-porphyry with little blebs of quartz. These average about $\frac{1}{10}$ inch in diameter, and have the usual "corroded" appearance, with enclosures of the groundmass, which is almost cryptocrystalline [1156]; there are, moreover, clusters of small porphyritic felspars like those noticed above. The upper sill has to the eye a much more lamprophyric appearance.

Not far east of Gill Farm is a large dyke which has all the appearance of an ordinary minette. No quartz is evident, but there are small porphyritic felspars, usually not more than $\frac{1}{2}$ inch long; some light red, others, with rounded edges, colourless and glassy. These latter are found under the microscope to consist of striated plagioclase with a narrow border of orthoclase, like those noted in the third of the sills at Stakeley Folds. As before, the two felspars have Carlsbad twinning in common [1155]. The brown mica has the usual hexagonal habit, but its extinction in transverse sections is oblique enough to show vaguely the repeated lamellar twinning already remarked in the granite. The flakes are frequently bleached in the interior, in the fashion familiar in the mica-traps of various districts. The inclusions of zircon, apatite, &c. are sometimes ranged parallel to the basal plane. Magnetite occurs in rather large patches through the rock, as well as in numerous minute octahedra. The general ground consists largely of little felspar prisms, with a few more shapeless crystals of concentrically zoned felspar, and subordinate quartz. Except for the quartz in the groundmass, which seems to be at least in part an original constituent, this dyke compares closely with mica-traps such as those described by Prof. Bonney and Mr. Houghton * in the Kendal and Sedbergh districts, and by Dr. Hatch † near the latter locality, or with similar rocks to be seen near Ingleton and in the district west of the Cross Fell range.

Viewed as a whole, the set of neighbouring intrusions briefly described above, while presenting a considerable range of differences, have at the same time some curious points in common. Further, while they have characters which seem to connect them on the one hand with the Shap Fell granite, and particularly with its darker patches, they are unmistakably linked on the other hand with the normal

* Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 165.
† Brit. Assoc. Rep. 1890 (Leeds Meeting), pp. 813, 814.

type of "mica-traps" found at greater distances from the Shap Fell intrusion. For instance, the rounded quartz-blebs, which are found in all the Stakeley Folds rocks, occur occasionally in mica-traps as far away as Swindale, near Knock, 14 miles from the granite, although there the groundmass contains no original quartz. The Swindale intrusions, too, have here and there a crystal of felspar, either of the red or of the colourless glassy-looking kind, the edges showing the rounding already noted in our rocks. The "glomero-porphyritic" clusters of small felspars have been noticed by Mr. Tate * in one of the Ingleton dykes. At the same time, the special characters of the Stakeley Folds rocks are met with more rarely at greater distances from the Shap Fell granite. From Prof. Bonney's descriptions we gather that of the seventeen dykes examined by him (at distances of 5 to 14 miles from the granite), only one had original quartz-grains, and he adds that "their appearance suggests the possibility of their having been caught up by the molten rock."

We do not find in published descriptions anything to compare at all closely with the above group of intrusions as a whole. It may be worth noting that the well-known "porphyroïde" of Mairus in the Ardennes, described by MM. de la Vallée Poussin and Renard †, is a biotite-quartz-porphyry in which the porphyritic felspars show phenomena of rounding and bordering in some respects similar to those noticed above.

The largest dyke in this part of the district is one exposed on the moorland some four or five hundred yards south of Wasdale Old Bridge. It strikes in a nearly N.W.–S.E. direction, and is remarkable for containing porphyritic crystals of monoclinic felspar (in the form of partially-interpenetrating Carlsbad twins nearly two inches long). It has also porphyritic quartz in good crystals up to $\frac{1}{5}$ inch, showing prism- as well as pyramid-faces; and these occur in great numbers enclosed in the large felspars, as well as in the general mass of the rock. The felspars have a very pronounced tabular habit, parallel to the clinopinacoid, the thickness of a crystal being less than one-fifth of its length. The forms present are the usual clinopinacoid, prism, basal, and hemidome, with another form $(h\,k\,l)$ not determinable on the specimens. The mineral has a strong glassy lustre, and the third cleavage (parallel to the orthopinacoid) is well developed. These characters, with the tabular habit, are the chief mineralogical grounds on which sanidine is usually separated from orthoclase, and there seems to be no reason why these crystals should not be named "sanidine."

A number of other dykes, showing in some degree a radial arrangement about the granite, are marked on the Geological Survey map, and we have examined several of these between Shap Fell and Tebay, and farther west and south. In many cases the rocks are deeply weathered, and detailed descriptions would not be very profitable. It is sufficient to note that some are ordinary quartz-porphyries; others are normal mica-traps with no original

* Brit. Assoc. Rep. 1890 (Leeds Meeting), p. 814.
† Mém. couronn. Acad. Roy. Brux. (1876).

quartz—*e.g.* the dyke between Crookdale and Borrowdale [1163]; while others, again, belong to intermediate types—*e. g.* the dyke or series of dykes on Potter Fell [792]. In this latter rock, at a distance of six miles from Shap Fell, are found long flakes of dark mica with the blade-like habit of that noticed in some parts of the granite margin.

None of the various intrusions we have alluded to can be traced as continuous with the granite at the present surface. If we are right in regarding them as apophyses, they are in connexion, not with the visible granite mass, but with a deep-seated extension of it.

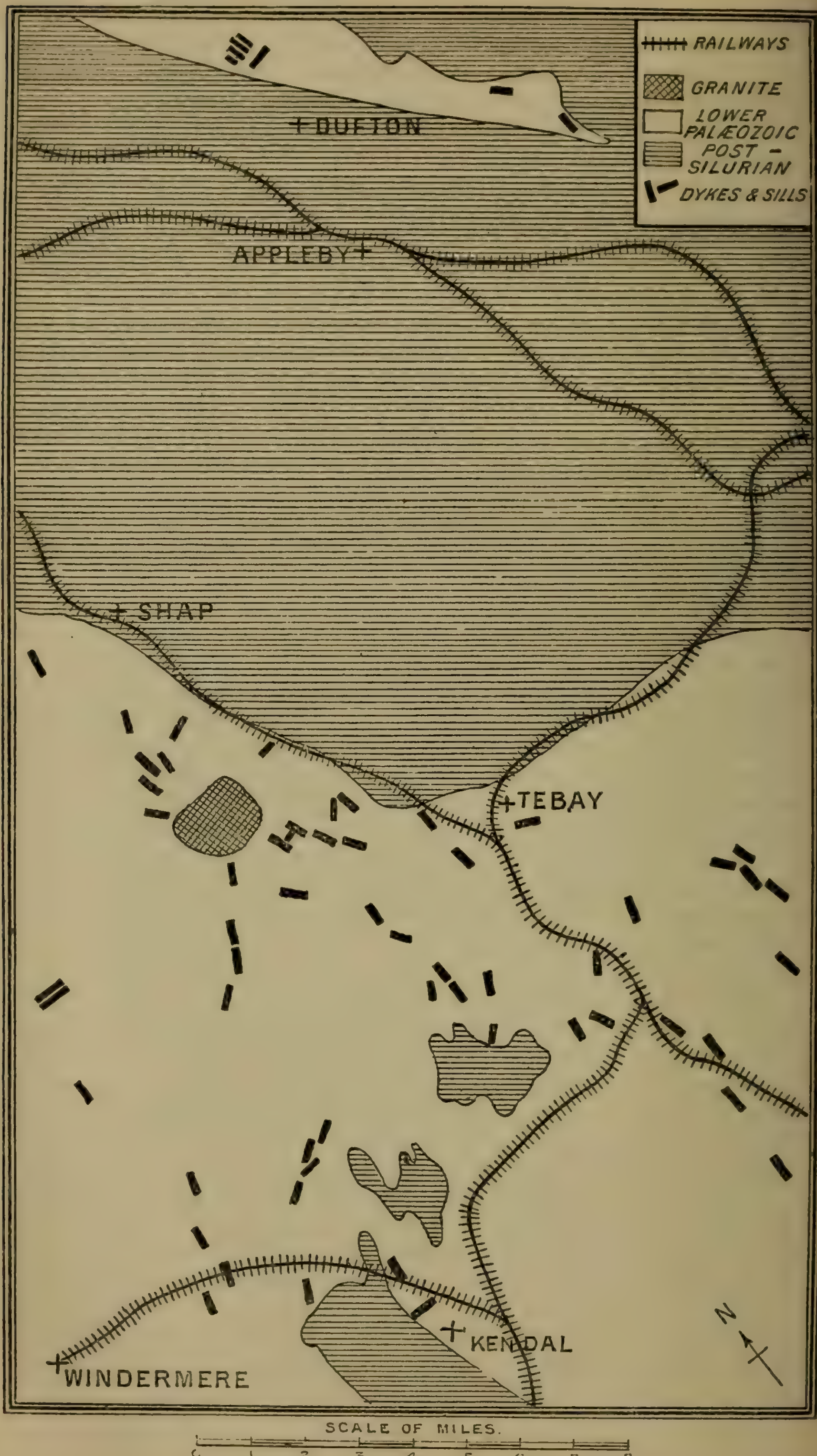
The small dykes found in close proximity to the margin of the granite outcrop, such as the two seen not far west of Wasdale Head Farm, are ordinary quartz-porphyries with no special peculiarities, except that they sometimes contain little crystals of brown sphene [757], an uncommon mineral in such rocks, though it might almost be expected in any offshoot of the Shap Fell granite. The same constituent occurs sparingly in the brown-coloured rock with porphyritic quartz and felspars which is prominent in the Blea Beck section, apparently forming an irregular sill at the summit of the Lower Limestone [882].

There is no doubt that many dykes which we have failed to observe exist to the north of Shap Fell. Such dykes would be less noticeable in the Volcanic Series than in the Silurians to the south, and the quarter-sheet of the Geological Survey map for the northern part of this district is not yet published *. Sedgwick found a quartz-porphyry not very different from that of Blea Beck in Wet Sleddale [803]. This may be a dyke or sill belonging to the inner group, connected at or near the surface with the Shap Fell granite. A large dyke belonging to the outer group of apophyses cuts the Skiddaw Slates at Goodcroft Farm, near Rossgill. It is about four miles north of the granite outcrop, towards which it bears directly. It is twenty to forty yards wide, and encloses entangled masses of indurated slate. The rock is a normal quartz-porphyry [1164].

When these apophyses are considered in conjunction with the patches of darker rock caught up in the mass of the granite, they appear to throw light upon the origin of several of the dykes which penetrate the Lower-Palæozoic rocks of the district, and which are thickly clustered in some areas, whilst they are much rarer in others. They abound within a radius of fifteen miles of the Shap granite (see Map, fig. 4, p. 290), whilst others are found in great numbers around the other granite areas. These latter are usually felsitic, whilst those more immediately in the neighbourhood of the Shap granite are both felsites and mica-traps, and, so far as we are aware, the latter are chiefly confined to the east end of the Lake District,

* [Since this paper was read we have, by kind permission of the Director-General, compared our map with the six-inch MS. map in the Survey Office, and inserted several additional dykes in the country north of the granite.—March 11th, 1891.]

Fig. 4.—*Sketch-Map showing the Distribution of Dykes and Sills around the Shap Granite.*



and to the Cross Fell, Sedbergh, and Ingleton areas, and do not occur around the Eskdale granite, though the minette of Sale Fell and the mica-traps of Dodd are near the granite of Skiddaw. Both the felsitic and micaceous rocks have abundant porphyritic felspars in the neighbourhood of the Shap granite, as we have shown in our description of the rocks from Stakeley Folds and elsewhere, and these felspars are in every respect so similar to those of the granite itself that it seems impossible to disconnect them from that mass, especially as we find that the felspars abound near the granite contact, and become rarer as we recede from this, whilst at the same time the more distant dykes show other indications of having consolidated at a greater distance from the then deep-seated magma, as evidenced by the occurrence of vesicles in the dyke at Castle How, near Tebay, which contains few porphyritic crystals. We have already pointed out the resemblances between these dykes and sills and the dark patches included in the granite. It would seem that a magma occurred beneath the Shap granite of a more basic character than the granite itself, and that from this the micaceous dykes were sent out, whilst the more acid portion of the magma was injected into rocks at a higher level than the main source of supply to form the Shap granite and the felsite apophyses, portions of the more basic part being carried up as "clots" in the granite, constituting the dark patches contained therein. In favour of this view, we may note that the evidence points to the Shap granite and the mica-traps having been formed at the same geological period, as shown by the intrusion of undoubted apophyses of the granite along with mica-traps in rocks of late Silurian age, whilst the pre-Carboniferous age of both the granite and the mica-traps is generally recognized. From the great abundance of mica-trap dykes it is evident that a magma like that which we suppose to have existed at a lower level than the Shap granite must have been situated at some point below this region, and the strong resemblance of the micaceous dykes of Stakeley Folds and the Gill to the patches in the granite almost certainly demonstrates that they have had a common source.

The possible presence of this more extensive magma underneath the Shap granite, and at one time connected with it, is of great importance in discussing the origin of the actual granite mass. In connexion with the foregoing observations, a few remarks concerning the nature of the intrusive mass of Shap seem to be necessary, though, in the absence of any certain knowledge, our comments must be brief.

We have attempted to show that the Shap granite is merely a subsidiary offshoot of a deep-seated igneous mass of much greater extent. It is interesting to observe that just as the Shap granite occurs at the point of contact of two sets of disturbances, viz. that which has produced the normal strike of the Lake District rocks, and that which gives the beds associated with the Skiddaw Slates to the west of the village of Shap a general N.W.-S.E. strike, so the principal dykes which we have attempted to connect with the

deeper-seated magma occur where the above-mentioned normal strike is complicated by the great fractures ranging down the Lune Valley in the neighbourhood of Tebay and Sedbergh.

We are now confronted with the question, what is the nature of the Shap intrusion itself? It does not appear to be a simple laccolite, and, on the other hand, we have seen that several sills are protruded from it around the margin. The strike of the rocks may have been bent by the granite, or, on the other hand, the intrusion may have taken place in a region where a weak place was caused, owing to the bending of the rocks. The usual greater density of the altered rocks seems to indicate some compression, though whether this and the preceding cause would be sufficient to leave space for the granitic intrusion is doubtful.

On the other hand, the abnormal alteration of the rocks around a mass with so small a diameter would suggest the passage of molten matter for a considerable period through the channel which is now filled with granite, though whether this channel ever communicated with the surface, giving rise to volcanic outbursts similar to those which occurred in regions farther north during Old Red Sandstone times, we have no evidence to show.

On the whole, the phenomena presented here seem to us to be most easily explicable upon the supposition that molten matter was for a long period forced from the underlying magma through a channel which may have been "punched out" in the way suggested by Dr. Ch. Barrois in the case of the Rostrenen granite *, and that it finally consolidated therein in the form of a "cedar-tree" laccolite, *i. e.* in a form corresponding with that of the gabbro shown in the theoretical representation drawn by Dr. A. Geikie †.

Lastly, in connexion with the deep-seated magma, one naturally recalls the magnetic observations of Profs. Thorpe and Rücker ‡ on the occurrence of a "ridge" in the neighbourhood of Appleby; but when we consider the subsequent injections of more basic rock in the neighbourhood, such as the Great Whin Sill, which was also doubtless connected with deeper masses of a somewhat similar nature, we are not inclined to lay much stress upon the coincidence.

## § IV. Metamorphism of the Surrounding Rocks.

### A. *The Andesitic Group.*

The lowest rocks affected by the granite intrusion are those which may be classed as andesitic. Owing to the anticlinal folding described above, this group occupies a considerable area of ground to the north and west of the granite, being in contact with the intrusion around one-half of its circumference. The total thickness of the andesitic lavas is probably made up of a succession of comparatively thin flows: this is inferred from the fact that the rocks

* Ann. Soc. Géol. du Nord, vol. xii. (1885) p. 105.
† Trans. Roy. Soc. Edin. vol. xxxv. (1888) p. 142.
‡ 'Nature,' vol. xli. p. 598 (April 24th, 1890).

are vesicular throughout, and it is verified in one or two places where ash-bands are interbedded with the upper part of the lavas. The heterogeneous nature of the materials which constitute pyroclastic rocks makes it, however, difficult to classify them strictly into families. The ashes included here have probably a composition not very different from that of the andesitic lavas, and give rise by metamorphism to almost identical products, but they are not very sharply marked off from the overlying rocks which we place in the Rhyolitic Group.

Examined at a distance from the granite, as, for example, in Stockdale, the andesitic lavas are found to have suffered considerable changes by the ordinary processes of weathering. These changes—the destruction of the augite, the filling of the vesicles with secondary products, and the formation of little veins of calcite and quartz—date from a time anterior to the intrusion of the granite. This fact is abundantly proved by an examination of the metamorphosed rocks, and is essential to the interpretation of their phenomena. It must be remembered that this part of the Volcanic Series was perhaps subaërial, and rocks of this character were certainly exposed to denudation while the Coniston Limestone was being accumulated.

A section of the weathered andesite of Stockdale shows crowds of little felspar-prisms embedded in a pale green decomposition-product which appears to represent ophitic augite. The felspar may be referred by its extinction-angles to a variety near andesine in composition. A few larger felspar-crystals are scattered through the rock, and all are more or less turbid owing to secondary changes. The pale-green mineral polarizes in deep indigo tints, and shows the properties which seem to belong to delessite. There are none of the little bastite pseudomorphs so characteristic of decomposed rhombic pyroxenes in the hypersthene-andesites. There are apatite prisms and a few magnetite crystals of rude form, besides a certain amount of secondary magnetite-dust contained in the delessite. A little dust of calcite is also present, and a considerable amount of silica has been set free in the form of quartz.

The ovoid vesicles vary in size from one-twentieth of an inch to one or even two inches. The smallest ones are filled sometimes with quartz, sometimes with the pale-green product referred to delessite, which has a regular radiate arrangement. Others are lined with this substance, and have their interior occupied by confusedly crystallized quartz. The larger ones may have detached radiate aggregates of delessite in their centre, or more irregular patches due to the breaking away of the lining from the wall of the cavity before the silica was deposited. Other vesicles, again, are partly or wholly occupied by calcite, usually in a single crystal, and this kind of amygdule may often be seen side by side with the others here mentioned.

In a typical specimen of andesite taken between Wasdale Pike and Great Yarlside, where the metamorphism has been but slightly felt, Mr. Garwood finds 59·95 per cent. of silica. This confirms the

character of the rock, and compares closely with the figures found for other Lake District andesites. Two rocks from Mr. Clifton Ward's Falcon Crag section (near Keswick) gave 60·718 and 59·511 per cent., and one from Lingmell Beck, about two miles north-west of Scawfell Pike, 59·151 per cent. To these we may add a large boulder at Manfield, near Darlington, doubtless from the Lake District, in which Mr. W. F. K. Stock found 59·87 per cent. of silica *.

The andesitic lavas afford some of the most beautiful and instructive examples of thermo-metamorphism in the district, and as they can be followed along their line of strike from localities free from alteration into the "contact-aureole" and up to their junction with the granite itself, the process of transformation can be traced in all its stages.

At places at considerable distances from the junction, such as Little Saddle Crag (1350 yards), we notice that the vesicles contain a quantity of epidote in addition to delessite, quartz, and calcite [1277, 1278]. In some districts epidote has been recorded as a product of thermal metamorphism, but we cannot satisfy ourselves that in these andesites it is other than an ordinary result of weathering action. Setting it aside, the rocks at the locality in question give no marked indication of metamorphism by the granite. Proceeding eastward, however, we find substantial alteration setting in, being first shown in the weathering-products of the original rock. A specimen taken some distance west of Wasdale Pike, and nearly 800 yards from the granite-boundary, is crowded with minute flakes of brown mica, apparently developed at the expense of the decomposition-product (delessite ?) disseminated through the weathered andesite [1205]. In the vesicles part of the delessite is altered into green hornblende, while part remains unchanged (see Pl. XI. fig. 4). A little farther east (at 750 yards) the flakes of brown mica are rather larger and more collected [1204]. The pale green product in the vesicles is still only partially altered, and a little epidote is still present, but this mineral is not found nearer to the granite.

The formation of brown mica, which, it will be seen, is the most characteristic mineral in the altered andesites, is thus the first clear result of the metamorphic action, while, almost concurrently with it, green hornblende begins to appear among the contents of the vesicles. The greatest distance at which we have verified metamorphic action is 1150 or 1200 yards, on Low Fell, where the mica-flakes are chiefly collected about little grains of magnetite, a frequent occurrence in such rocks [1279].

In the field the early stages of metamorphism are indicated chiefly by the vesicles, in which lustrous, greenish-black aggregates of hornblende are to be detected by the eye. Proceeding towards the contact, the hornblende becomes more distinctive, showing good cleavage-planes, while the quartz filling other vesicles takes on a

* 'Naturalist' (1889), p. 304.

whiter and more evidently crystalline appearance, and stands out like pebbles on a weathered surface, often enclosing a kernel of hornblende. At the same time the dull grey ground of the rock becomes blacker and more compact, and often contains greenish crystalline streaks of hornblende, or more rarely a pyroxenic mineral in its place. Pyrites is of common occurrence in these streaks and in the interior of some of the vesicles. The dark colour of the rock is due to the development of mica, and nearer to the granite this mineral imparts a brown or purplish-brown sheen to the rock, and eventually becomes apparent to the eye. Near the contact the vesicles lose something of the distinctness of their external boundaries, their contents being to some extent merged in the general recrystallization of the rock.

The microscope brings out more clearly the nature of the transformations undergone by these rocks. The chloritoid substance which we identify with delessite is found to have disappeared completely in the thoroughly metamorphosed specimens. It is replaced most frequently by a deep brown, intensely dichroic mica, which is disseminated through the rock in very minute flakes, with occasionally a few larger ones in clusters and patches. This mineral occurs almost universally, but is not uniformly distributed. Instead of it in some parts of the sections we find a green hornblende, in crystalline grains of varying size, showing the prismatic cleavage-traces, and giving the usual absorption-formula:
$\gamma$, grass-green; $\beta$, a slightly less deep green; $\alpha$, pale yellow-brown;

$$\gamma \underset{>}{=} \beta > > \alpha.$$

With the hornblende, or locally replacing it, is seen occasionally a green fibrous actinolite in characteristic sheaf-like bundles. These amphibole-minerals are very generally confined to streaks varying from a very narrow width to half an inch or an inch, so that a slide may show hornblende as the characteristic mineral in one half of the field and brown mica in the other. Less common is a pyroxenic mineral, colourless in thin slices and having the general characters of monoclinic augite. It occurs in well-cleaved crystalline grains with the hornblende, and less frequently a vein is seen consisting entirely of a mosaic of crystalline augite [759].

Magnetite is a very common mineral, usually building minute but rather perfect octahedra. It is associated more frequently with the hornblende than with the brown mica, though the latter mineral sometimes encloses a few grains of magnetite also. Pyrites * is another mineral having the same association. It forms little cubical crystals or irregular patches. More remarkable is the very frequent occurrence of sphene, almost always in those parts of the altered rocks which contain hornblende. The sphene is in little rounded grains or clusters of minute granules, less commonly in rather imperfect crystal forms. It exhibits unusually strong

* Judging from the colours in reflected light, both pyrites and pyrrhotite occur, but it would be very difficult to isolate the little granules for examination.

pleochroism, between purplish-brown and colourless. Apatite occurs very rarely in little veins of quartz and mica, in a fashion which seems to indicate a metamorphic origin [798].

The above-mentioned minerals collectively make up a considerable part of the metamorphosed andesite. The remainder of the rock consists of a finely granular groundmass, the precise nature of which is less easily studied. A portion of it is quartz, but careful scrutiny detects here and there in the grains the evidence of twinning and even of twin-lamellation. It is doubtful in some cases how much of the original felspar of the andesites is preserved as such in the less metamorphosed examples. The process of reconstruction is seen, however, in some of the occasional porphyritic felspars. One of these will be found to be studded with little flakes of brown mica and partly transformed into a granular aggregate, while enough of the original felspar-substance remains to vaguely indicate the twinning between crossed nicols [799]. In the vicinity of the granite, the whole substance of the rock is certainly transformed, and the granular aggregate in which the coloured minerals are embedded assumes the perfectly clear appearance so well seen in many "crystalline schists." The twinning of the granules can be verified only occasionally, although it is evident from chemical considerations that a considerable proportion of the aggregate must consist of felspar. These highly altered rocks share with many of the products of dynamo-metamorphism their singular immunity from subsequent secondary changes, a property which seems to require some physical explanation. It is curious to compare in a junction-slice of altered andesite and granite the fresh minerals of the former with the turbid felspars and discoloured micas of the latter.

The contents of the vesicles and of certain narrow cracks posterior to the filling of the vesicles have undergone instructive transformations. It is here that the first effects of the metamorphic agent were manifested. The silica is found to have recrystallized in a mosaic of clear quartz-grains, free from fluid-cavities. In the less metamorphosed examples this process is incomplete, the central portion retaining its confused, almost cryptocrystalline, structure. In the highly altered rocks the change to a rather coarsely-granular mosaic is universal, and this at its outer boundary is not very sharply separated from the surrounding rock.

The delessite is here almost constantly replaced by the green hornblende described above, the brown mica occurring but rarely either in the vesicles or in the occasional narrow veins which represent cracks in the rock [798]. The vesicles contain hornblende even when the surrounding rock is densely charged with flakes of mica (see Pl. XI. fig. 5). The hornblende is well-cleaved, and sometimes the whole or a large part of the mineral within one vesicle is in crystalline continuity. One slide [897] shows one of the narrow veins alluded to running straight through the section. It contains clear quartz or, in some parts of its length, hornblende. The vein traverses two vesicles, and in each case the

portion of it within the vesicle is occupied by hornblende in crystalline continuity with the adjacent hornblende.

Little magnetite-crystals are not infrequently found in the altered vesicles, and sometimes pyrites. Sphene occurs in both the vesicles and the narrow veins, usually in round granules, occasionally in a characteristic acute-angled crystal. The metamorphic origin of all these minerals is abundantly proved by their manner of occurrence. In one instance only was a minute garnet found embedded in a quartz within the vesicle [759].

Felspar does not appear to have been commonly formed in the metamorphism of the contents of the vesicles. One slide only shows good crystals of that mineral, often twinned, occupying a considerable portion of some of the cavities, and accompanied by brown mica instead of the customary hornblende [1203]. This specimen was taken north of Wasdale Pike, about 400 yards from the nearest outcrop of granite. The felspar is here moulded by the mica, and occupies the marginal part of the vesicle (see Pl. XI. fig. 6).

The weathered andesites before metamorphism appear to have been traversed in places by little veins of chalcedony. One slide [1205] shows such a vein, now transformed into quartz, but retaining the mamillated form of deposit so characteristic of chalcedonic infiltrations. Other specimens, nearer to the granite, show veins of quartz-mosaic, which may or may not represent altered chalcedony, but are evidently recrystallized during the metamorphism of the rocks. Among other inclusions, this quartz contains minute patches of brown mica with rounded outlines [1201].

In the field the altered andesites sometimes show silvery mica on planes which seem to have been joints in the rock prior to the metamorphism,—a feature observed in some other rocks near the Shap Fell intrusion.

The distribution and association of the various minerals met with in the metamorphosed andesites seem to admit of a certain amount of explanation on chemical grounds, supposing that the substances formed at any point within the mass depended on the chemical composition at that point of the weathered andesite prior to the metamorphism. The phenomena described above, and especially those connected with the altered vesicles, sufficiently prove that considerable weathering had already taken place. It appears that the augite had been completely, and the felspars partially, destroyed, with the formation of quartz, calcite, and a chloritoid mineral as the chief secondary products. In accordance with their usual behaviour, the chloritoid substance was mainly in pseudomorphs occupying the place of the augite, but probably disseminated also through some of the larger felspars; the secondary quartz was confined mainly to the felspars; and the calcite formed granular patches or collected in veins and streaks. The vesicles were filled with quartz, or with calcite and the green product, or with the usual associations of these minerals, as already mentioned.

Taking the chloritoid mineral to be delessite and the brown mica biotite, the addition of some silica and the loss of most of the

water would be almost the only changes involved in the conversion of the former into the latter mineral, and this appears to have been the usual mode of alteration in the rocks in question. To produce hornblende, however, would require the taking up of lime, as well as silica, and the distribution of this mineral in patches and streaks in the metamorphosed rocks, and particularly within the vesicles, seems to show that its formation, instead of biotite, depended upon the presence of calcite in the immediate neighbourhood of the delessite. Augite contains much more lime than hornblende, and its mode of occurrence as a metamorphic mineral accords well with our suggestion. The veins of pure augite [759] may be taken as representing veins of crystalline calcite traversing the weathered andesite before its metamorphism. The mineral is identical with that to be described below as one of the most abundant silicates in metamorphosed rocks of the calcareous group, and is presumably a variety rich in lime.

With respect to the sphene, it is not easy to say in what form the titanic acid existed before the metamorphism. Ilmenite does not appear to be a common constituent of the original andesites, though it occurs rather abundantly, with secondary translucent sphene, in some of the ashy beds [766]. The sphene, a lime-bearing mineral, naturally occurs in association with the hornblende and colourless augite rather than with the mica, but the titanic acid may have been distributed uniformly through the weathered andesite and be now partly contained in the last-named mineral. The biotite of Miask is known to have 4·73 per cent. of titanic acid *, and this substance is beginning to be recognized as a wide-spread constituent of the brown rock-forming micas.

The magnetite, again, is mostly found in association with hornblende, but it is possible that the other parts of the rock contain as much iron, which is there incorporated as part of the brown mica. The flakes of the latter mineral are too minute to allow of any precise study which might determine whether they should be referred to biotite, haughtonite, or lepidomelane. The strongly pleochroic brown mica of thermo-metamorphic rocks (*Hornfels*, &c.) is usually stated to be biotite, but we shall allude to this point again below.

The specific gravity of a highly-metamorphosed vesicular andesite from near the northern border of the granite was found to be 2·800, the figures for the non-metamorphosed rock in Stockdale being 2·736. We shall see that the metamorphism of the rocks around the Shap granite is in general accompanied, as in this case, by a condensation of bulk.

In this place we may most conveniently notice the metamorphism of certain ashes, fine agglomerates, &c., which are closely associated with the andesitic lavas. The fragmental volcanic rocks, having usually a heterogeneous constitution, do not admit of any very strict

* R. Schläpfer, 'Rech. sur la compos. des micas et des chlorites,' Schaffhausen (1889). See also Koch, Zeitschr. deutsch. geol. Gesellsch. vol. xli. (1889) p. 165; W. M. Hutchings, Geol. Mag. (1890) pp. 272, 273.

classification into rhyolitic, andesitic, &c.; but the rocks in question seem to be made up largely of pyroclastic materials of the same general nature as the associated andesites, and give rise when metamorphosed to very similar results. They are probably on the whole somewhat more "acid" in composition, since they frequently enclose rhyolite-fragments broken up by the explosive outbursts by which the accumulations were produced, and mingled with the fine dust, fractured crystals, and andesitic material.

The non-metamorphosed rocks of this type may be studied in Stockdale, Wet Sleddale, &c., where the influence of the intrusion has not been perceptibly felt. The recognizable fragments are partly crystals, partly pieces of lava. The crystals are similar to those which occur porphyritically in the andesites themselves. They very frequently lie with their length nearly at right angles to the lamination of the finer matrix, indicating that they have been dropped into their place [895]. This appears to be a characteristic feature of pyroclastic rocks, especially those accumulated on land, and affords a useful criterion in other districts where ashes and lavas, chiefly of acid type, have been altered (not by thermo-metamorphism) almost beyond recognition.

Some of the lava-fragments are of andesite, showing the usual densely-packed felspar-prisms, and occasionally enclosing small vesicles [875]. Others are of rhyolite, as already remarked. The matrix of the mass is usually a finely-divided clastic material. Its lamination is emphasized by the development along it of a pale-yellowish or colourless sericitic substance which winds past the enclosed fragments, and imparts a "schist"-like appearance to the sections. Crystals, fragments, and matrix have undergone the ordinary weathering processes, with the production of secondary quartz, the usual pale-green product, a little magnetite dust, and some calcite, which is more uniformly distributed than in the weathered andesite lavas.

Metamorphosed representatives of these rocks, which we may term andesitic agglomerates and ashes, are met with intercalated among the lavas at various horizons. The minerals produced are in general those already described in the metamorphosed andesites. Mica is the commonest of the coloured constituents. It is usually of the highly pleochroic variety already noticed, giving a very deep, rather greenish-brown colour for vibrations parallel to the cleavage-traces. Sometimes it has less intense absorption, and is apparently partly bleached [875]; or again, it is partially decomposed, giving a green colour with secondary dust of magnetite. There is, however, a rather different type of mica seen in some of the slides, having a more ruddy brown colour and giving:

$\beta$ and $\gamma$, chestnut-brown; $\alpha$, nearly colourless.

This mica, when partially decomposed, loses its cleavage and some of its pleochroism. Its characters would seem to indicate a variety having a different chemical composition from the former, but although the two types usually occur separately, they are in some

cases associated in the same flake. Hornblende and actinolite both occur with the same characters as in the metamorphosed andesites [902 and 875], associated with one another, and in one instance with colourless augite [902]; but here these minerals are much less abundant than the mica, which is commonly the only ferro-magnesian mineral present in the slides. Hornblende, however, occurs as usual in the metamorphosed vesicles of enclosed andesite-fragments [875].

Magnetite is found in octahedra and less perfect forms [796], but it is less abundant than in the metamorphosed andesites, and is often wanting in those specimens most rich in mica [896, etc.]. Sphene has not been observed. These facts accord with the suggestions offered above; the titanic acid and most of the iron oxides contained in the rocks have been incorporated in the brown micas.

The remainder of the rock is a granular aggregate resembling that seen in the metamorphosed andesitic lavas, though not quite so fine-grained. Twinning and twin-lamellation are to be observed between crossed nicols, and it is evident that a large part of the rock consists of reconstituted felspar. This is brought out also by a certain amount of turbidity in the felspars, distinguishing them from the clear quartz, which they sometimes mould. It is noticeable in these metamorphosed andesitic rocks that the originally fragmental examples show signs of subsequent weathering which are not found in the associated lavas.

The embedded felspar-crystals have been replaced by an aggregate of new felspar and quartz, with more or less brown mica, and exceptionally a considerable quantity of yellow epidote [900]. In the less metamorphosed examples the original twinning can be vaguely discerned; in specimens taken close to the granite-junction the structure is totally destroyed, and the pseudomorphs are recognized merely as areas poorer in mica than the surrounding rock.

The character of the metamorphosed andesitic ashes and agglomerates is sufficiently indicated by the foregoing remarks. It only remains to be said that there is often a marked laminated structure well indicated by the parallel disposition of the flakes of mica [797, 896], and increasing the general resemblance of these highly altered rocks to true crystalline schists.

In the thermo-metamorphism of rocks in the vicinity of an igneous mass, it is an important question how far the total chemical composition has been modified by the changes produced. To give a satisfactory solution of this question would demand a detailed chemical investigation. With respect to the andesitic rocks of Shap Fell, Mr. Garwood has examined for us specimens of highly altered andesite and ash from near the northern margin of the granite, and finds that they contain only 50·75 and 50·90 per cent. of silica respectively; *i. e.* 9 per cent. less than the non-metamorphosed andesite. This apparent loss of silica is a fact for which we are unable to offer any explanation. There is no stratigraphical reason to suppose that the specimens analysed differed in their original composition from normal augite-andesites such as those

of Stockdale, but they probably do not occupy quite the same horizon.

Thermo-metamorphism in andesitic rocks has hitherto received but little attention. Prof. Judd * has adverted very briefly to some changes of this kind in the andesites or "propylites" of the Western Isles of Scotland. He alludes to the formation in the contact-zones of colourless secondary pyroxene, magnetite, and deep brown biotite, with possibly melilite and felspar; but we do not gather that these phenomena are exhibited on any extensive scale. As regards the metamorphism by heat of augitic rocks in general, the first important record is that of Mr. Allport †, who showed that in the neighbourhood of the Cornish granites the augite of the "greenstones" has been replaced by hornblende and actinolite. It appears from his description, and from the only Cornish examples we have examined, that there, as in the Shap Fell andesites, much at least of the augite must have been converted into secondary minerals before the metamorphism [1129]. Prof. Lossen ‡, however, describes appearances in the metamorphosed diabases in the Harz, which leave no doubt as to the direct "uralitization" of augite under the influence of a granitic intrusion; and a series of slides from specimens taken near Rosstrappe, Thale, one of his typical localities, show that hornblende has been formed both directly from augite and also from its decomposition-products [469–473]. The officers of the Geological Survey of Saxony § have described the conversion of diabases into actinolite- and anthophyllite-schists around the syenite of Meissen.

## B. *The Rhyolitic Rocks.*

The rhyolites of the district, whether associated with or underlying the Coniston Limestone, have characters familiar to geologists who are acquainted with Ordovician volcanic rocks in other parts of Britain, and we do not propose to enter into many details with respect to their general features. Moreover, owing to their comparatively simple chemical and mineralogical constitution, they do not present such diversities in their modes of metamorphism as have been described in the case of the andesites. In the field, indeed, the rhyolites seem to show little or no change, as they are traced along their strike into the aureole of metamorphism; but this idea is dispelled by a closer study of the specimens.

At a distance from the granite, the rhyolites may be studied in Stockdale and Long Sleddale. They often have a grey colour with a rather flinty appearance; when this is wanting, they are pink or cream-coloured, but always of compact texture. One type is laminated parallel to its flow-lines, and often has a fissile structure in

* Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 370.

† *Ibid.* vol. xxxii. (1876) p. 418.

‡ 'Erläut. zur geol. Specialk. Preuss.,' Blatt Harzgerode (1882), pp. 79, &c.

§ 'Erläut. zur Specialk. d. Königr. Sachsen' (1889), K. Dalmar, Section Tanneberg, Blatt 64; A. Sauer, Section Meissen, Blatt 48.

the same direction. Another is coarsely nodular, the spheroidal nodules varying from an inch to a foot in diameter. Such nodular rhyolites are well known in other districts, and have been discussed by one of us in the case of the Ordovician lavas of Caernarvonshire *. The alterations there described in what appear to have been giant spherulites, and in particular their partial and total replacement by cryptocrystalline silica or quartz, are exhibited on a magnificent scale on Great Yarlside and at other localities in our district. The peculiarity is not confined to true lava-flows; for an apparently intrusive rock in Blea Beck plantation, near Shap Wells, contains good silicified spheroids.

The rhyolites are never notably porphyritic, resembling in this and other respects the corresponding rocks in North Wales. Indeed the microscope shows that much of the material of the rocks was but very imperfectly individualized into felspar and quartz, presenting rather the features which are referred by many English petrologists to devitrification. Vesicles are found in these rocks only rarely, and they are usually of microscopic size.

An idea of the chemical composition of the rhyolites may be gathered from Mr. Garwood's analyses given below; the figures for two Caernarvonshire rocks are quoted for comparison. It will also be seen from columns I. and II. that, whatever metamorphism has operated in the rhyolite near the granite-contact, it has not materially affected the bulk-analysis of the rock.

The specific gravity of the specimen (I.) analysed is 2·608, which agrees exactly with that of similar rocks from North Wales. One of the most metamorphosed rhyolites from Wasdale Head gave 2·623, showing no great difference.

| | I. | II. | III. | IV. |
|---|---|---|---|---|
| $SiO_2$ ......... | 75·95 | 76·95 | 74·88 | 77·5 |
| $Al_2O_3$ ......... | 13·77 | 15·50 | 12·00 | 9·7 |
| $Fe_2O_3$ ......... | 3·48 | 2·00 | 3·50 | 6·1 |
| FeO ......... | not estim. | not estim. | 0·20 | not estim. |
| MgO ......... | trace. | ... | 1·28 | ... |
| CaO ......... | 0·25 | 1·05 | 0·34 | ... |
| $Na_2O$ } by difference | 6·55 | 4·50 | 2·49 | 0·3 |
| $K_2O$ } by difference | | | 4·77 | 5·8 |
| (Ignition) } by difference | | | 1·20 | 0·4 |
| | 100·00 | 100·00 | 100·66 | 99·8 |

I. Spherulitic Rhyolite, Stockdale; anal. E. J. Garwood.
II. Nodular Rhyolite, close to granite, near Wasdale Head Farm; anal. E. J. Garwood.
III. Rhyolite, Pitt's Head, 2½ miles S.W. of Snowdon; anal. J. Hughes, Trans. Roy. Ir. Acad. vol. xxiii. (1859) p. 615.
IV. Rhyolite, Cwm-silyn, above Nantlle Valley; anal. E. Hamilton Acton and J. T. Hewitt; 'Bala Volc. Ser. of Caern.' (1889) p. 13.

A very characteristic rock is that which forms the lower part of the Coniston Limestone rhyolite at Stockdale and Long Sleddale. It is of the laminated, fissile variety, the overlying rock being

* 'The Bala Volcanic Series of Caernarvonshire' (1889), chap. iii.

nodular,—an arrangement noted in some other localities also. This laminated rock has a typical microspherulitic structure, being almost entirely built of densely-packed minute spherulites, each of which gives a distinct black cross when a section is examined between crossed nicols [861]. In some places the growth, instead of being centric, is linear, and then follows the lines of flow. Slighter differences in structure in different parts of the slide also follow the fluxion-lines. A beautiful figure of this rock, showing the microspherulitic and perlitic structures, has been given by Mr. Teall *, and the same rock has been described and figured by Mr. Rutley †. The latter author has expressed the opinion that the spherulitic structure is here an effect of devitrification subsequent to the perlitic cracking; but we are unable to see that he has given any reasons for this view. The practice of assigning a secondary origin to special structures in the older acid lavas has perhaps been pushed to excess in some quarters. In the Westmorland rhyolites there are traces of perlitic fissures traversing rocks which are now microcrystalline, and other appearances pointing to the alteration of an originally glassy mass; but we find nothing to suggest that the spherulitic and allied structures are of formation posterior to the consolidation of the lava; and the breaking up of the vitreous material of the rocks examined seems to have been in many cases a chemical, not merely a molecular change.

In addition to occasional small crystals of quartz and felspar—mostly plagioclase—the only original minerals found in these rhyolitic lavas are scattered magnetite-crystals, and very rarely prisms of apatite [802]. Probably a little augite or biotite formed part of the original rocks, but a few scraps of the usual pale-green decomposition-product are the only thing to indicate the former presence of these minerals. Another secondary constituent is a yellowish-brown filmy mineral, like sericitic mica, which usually occupies perlitic cracks.

A frequent type of alteration in the rhyolites, shown in many of our specimens, is what we may conveniently term "silicification." The groundmass of rocks so affected presents a finely crystalline appearance, and consists mainly of quartz in a fine-grained mosaic, passing in irregularly disposed patches into a rather coarser grain. Included crystals of felspar are frequently pseudomorphed by a similar quartz-mosaic, and the process is sometimes made very evident by portions of the twinned crystals remaining still unaltered [802]. The occurrence of these silicified rhyolites shows no relation to the proximity of the granite, and we do not ascribe it to metamorphism by the agency of the intrusion. Identical phenomena are observed in various localities in Caernarvonshire remote from any igneous intrusion, and Miss Raisin ‡ has suggested a "percola-

* 'British Petrography' (1888), pl. xxxviii.

† Quart. Journ. Geol. Soc. vol. xl. (1884) p. 345, pl. xviii. fig. 6; Mem. Geol. Surv. (1885), 'The Felsitic Lavas of England and Wales,' p. 12, pl. ii. fig. 1.

‡ Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 267.

tion of heated waters carrying silica in solution" during a "Solfatara-stage" which may have marked the decline of Ordovician vulcanicity in the area. Whether this explanation hold good or not, it is difficult to believe that the alteration observed in some of these rocks could be effected except by the introduction of silica in some manner; and this addition of silica from without probably explains the high percentages of that substance found in some published analyses of rhyolites.

Passing on to the thermo-metamorphism of the rhyolites, we find a few points worth recording. Specimens taken north and east of the spot marked "Tunnel," at distances of about 600 or 700 yards from the margin of the granite, have suffered some alteration of the groundmass, which is in places of a microcrystalline texture, showing felspar as well as quartz. This is apparently quite reconstituted, but curving perlitic cracks are still clearly evident throughout the mass, marked out by micaceous films. The rock here encloses small porphyritic felspars, which are either quite unaltered or partly silicified, as mentioned above. One specimen has numerous vesicles, which are filled by crystallized quartz, partly idiomorphic; and there is no evidence that this quartz has recrystallized under metamorphic action [801].

Near Wasdale Head Farm the rhyolite may be examined close to its junction with the granite, and here more distinct evidences of metamorphism are obtained. Some specimens show a microcrystalline aggregate of recognizable clear felspar and quartz, similar to that noticed in the metamorphosed andesites, and leaving no doubt that the whole has been reconstituted by metamorphic agency [907]. Other examples seem to have been silicified prior to the intrusion of the granite, and the quartz which forms most of their bulk cannot be stated with certainty to have recrystallized during the metamorphism [880, 881]. The same is true of the quartz-veins which traverse some of the slides, the quartz in them often showing partial crystal contours. Besides quartz and felspar, these metamorphosed rhyolites have minute flakes of pleochroic brown mica and some colourless mica giving brilliant interference-colours. Larger flakes of brown mica occur, grouped in a fashion which suggests their derivation from the pale-green decomposition-product seen in some of the non-metamorphosed rhyolites. A pyrites-mineral, in good crystals, is an occasional constituent of these altered rocks [881].

The nodular rhyolites show considerable modifications in specimens taken near the granite. They must have undergone, before metamorphism, the process so common in these rocks, by which some of the constituents of the nodules became segregated into concentric shells, and these have been variously affected by the metamorphism. We find some bands in the sections consisting almost entirely of moderately coarse quartz-mosaic, with a little mica, either dark or pale, and occasionally crystals of blue tourmaline [907]. These correspond to the flinty shells seen in the nodules of many rhyolites, the silica, which was probably cryptocrystalline, having been trans-

formed into thoroughly crystalline quartz. Such bands alternate in the slides with others composed of a minutely crystalline aggregate of felspar and quartz, probably representing shells of rhyolite, which had not been much altered before the metamorphism. Again, parallel with these alternating zones there are sometimes strings of mica-flakes, mostly brown, but some colourless, which seem to answer to the well-known shells of the substance which Mr. Grenville Cole has compared with "pinite."

We now come to the rocks which we have classed as rhyolitic ashes and breccias. Owing to the much faulted state of these rocks and the want of continuous sections in some critical places, the precise succession in the Rhyolitic Group is a matter of inference rather than of demonstration. The order of the rocks actually exposed seems to be as follows, in descending order :—

Rhyolite, faulted against the Lower Coniston Limestone in Blea Beck.

Breccias and ashes, seen in the Summit railway-cutting and to the south, and on the moor west of the Hotel; these in Blea Beck rest on

Rhyolites, east of Blea Beck Bridge.

Fine ashes seen beside the old road to the north of Blea Beck Bridge; these have an abnormal strike (east and west) and their horizon is therefore rather doubtful.

Rhyolites, with subordinate fine ashes, covering the tract north of Blea Beck between the old and new high roads.

Fine ashes, with subordinate breccias, seen on the eastern margin of the granite and on the high road and neighbouring moorland; also on the west side of the granite, occupying the ground from Wasdale Pike to near Wasdale Head Farm.

On the whole the fragmental rocks of the upper part of the group, which are entirely missing on the west side of the intrusion, contain a larger proportion of macroscopic fragments, mostly of pink rhyolite, than those of the lower part, so that, in the field, we have termed many of them breccias; but the presence of these relatively large fragments in the fine matrix is the only character to distinguish the breccias from the associated rocks mapped as ashes. The rhyolite fragments are often angular or subangular, as in many similar rocks throughout the Lake District, and are clearly the results of explosive volcanic action. A comparison of the numerous rocks of this type in the Borrowdale series seems to show that the fragments cannot in general be ascribed to rhyolitic lava-flows broken through by the eruptions, but must represent a shattered crust of rhyolite formed within the volcanic vents.

The fragments in our breccias are by no means so exclusively composed of acid lava as might be supposed from the prominence of the pink rhyolite upon the dark matrix. Andesite is also well represented, in fragments of generally subangular or rounded form, besides occasional pieces of quartz-porphyry [1076, &c.], abundant

crystals of felspar, often silicified, quartz, magnetite, &c. The rolled appearance of some quartz grains and other fragments seems to indicate a detrital source for part of the material, and there can be no doubt that most, if not all, of these rocks were formed under water.

In the ashes of the lower part of the group, the fine matrix encloses only a few minute grains of quartz and occasional felspar-crystals, but in some of the upper fragmental rocks of the group we find a coarser-grained mass wherein identifiable fragments of minerals and rocks are in excess of the matrix which unites them [1073]. Despite such variations as this, it will be best to consider the whole of the ashes and breccias together, with respect to the effect on them of the metamorphic action produced by the granite intrusion. Even the rocks seen on the moorland west of the Hotel, some of which would be described as ashy grits rather than ashes [1074, 1075], show in their matrix the same metamorphic changes as the ordinary fine-grained ashes.

The fine ashes and the matrix of the breccias, when not extensively altered, present the same general characters as the ashy beds associated with rhyolitic lavas in other districts, such as North Wales. There is usually a distinct lamination, rather wavy so as to resemble a flow-structure, and this is often marked out by films of a colourless or yellowish sericitic substance [766, 767]. The general mass, consisting of very finely divided material probably analogous to volcanic dust, offers no special peculiarities. The decomposition-products are of the ordinary kind and often include a considerable quantity of epidote. The embedded felspar-crystals especially are in some of the rocks completely pseudomorphed by aggregates of greenish-yellow to colourless epidote, but we see no reason to connect this mineral with metamorphic action in the ordinary sense. More important is the formation of secondary quartz in the manner already noticed in the silicified rhyolitic lavas. This has taken place prior to the intrusion of the granite, and even in the inner part of the contact-aureole has to a great extent protected the rocks so affected from further changes.

The metamorphism of the rhyolitic ashes is in some respects comparable with that of argillaceous strata, such as the Brathay Flags, and it makes itself felt to about the same distances. The breccia of the Shap Summit railway-cutting shows no decided alteration of a thermo-metamorphic nature, the induration of the compact black matrix being attributable to a certain formation of secondary quartz, which probably took place before the date of the intrusion. This is at 1400 or 1500 yards from the granite. Farther south, a similar rock, though with fewer visible fragments, is exposed by the side of the footpath, about 1250 yards from the granite-margin, and this is within the metamorphosing influence. Under the microscope it shows at least a superficial resemblance to the spotted Brathay Flags described below in the occurrence of minute spots, about $\frac{1}{50}$ inch in diameter, free from the brown pigment which crowds most of the field [859]. The spots sometimes show between

crossed nicols a distinct crystalline reaction, polarizing in low tints like those of quartz. The brown colouring-matter is too minutely divided and too densely collected to admit of determination, but it is probably to be referred to mica. A similar substance is found in the metamorphosed fine pyritous ashes north of Blea Beck Bridge, and here it is certainly brown mica, the flakes being large enough for the pleochroism and other characters to become evident [869]. Here too, at 650 to 700 yards from the granite, the light spots are larger (up to about $\frac{1}{10}$ inch in diameter), but only the smallest of them behave in polarized light as single crystals. It may be remarked in passing that the andesite fragments in the breccias show the same development of brown mica as the matrix [1072, 1166].

There can be no doubt that the brown mica in these rocks is of metamorphic origin. It is absent in all specimens taken at places remote from the granite, and, up to a certain point, becomes more distinctly separated out, and in larger flakes, as we approach the intrusion. In some cases the mica is seen to have been formed especially in the neighbourhood of crystals of magnetite, from which the mineral presumably obtained the iron necessary for its composition. This is seen in some of the rocks which crop out on the moor west of the Hotel, about 1000 yards from the granite-boundary [1076]. Some of the rocks in this neighbourhood, however, show but little modification which can be ascribed to thermal action [1073], making it appear that the metamorphism does not depend in a very strict manner upon distance from the intrusion; but, in view of the faulted character of the ground, it would be unsafe to draw any conclusions from this fact.

We pass on to consider the more complete metamorphism of rhyolitic ashes seen in exposures nearer to the contact. About 250 yards from the eastern margin of the granite some highly altered ashes are exposed in a disused quarry on the old Shap road, and similar rocks crop out at one or two places on the neighbouring moorland. Almost every trace of original constitution is lost, but what remains is sufficient to show that the rocks were felspathic ashes. The lamination is indicated by the arrangement of flakes of brown mica and by streaks rich in opaque iron ores. The mica seems to have been derived from a green chloritoid mineral with low polarization-tints, some of which remains unaltered. The iron ores include ilmenite as well as magnetite, and occur as little crystals and minute granules having the appearance of metamorphic products. A clear colourless mica is sparingly present, and a characteristic mineral is disthene, of the pale blue variety known as cyanite, which is abundant in the slides in little imperfect crystals and clusters of granules. The bulk of the rock, however, consists of a fine-grained crystalline aggregate of felspar. The water-clear crystals mostly show some approach to rectangular contours, the cleavage is often well seen, and twinning is not uncommon; but we are not able to say with certainty that quartz is not present in subordinate quantity. It is evident, at least, that the bulk is of felspar, and that the whole was formed *in situ* during the metamorphism.

The optical characters of the grains seem to indicate orthoclase and albite. In a few places this groundmass encloses fine needles of a mineral with very high refraction and double refraction, straight extinction, and occasionally a faint brown colour; this seems to be rutile [905]. It will be noticed that in the andesitic rocks, with their higher content of lime, sphene was formed instead of rutile.

These ashes have had a few felspar crystals, up to about $\frac{1}{10}$ inch in length, scattered through the rock. The crystals are now for the most part replaced by new felspar substance, which does not preserve the original orientation; but enough of the old cloudy felspar remains to prove its nature and to show its twin-structure [904].

Rocks of similar appearance to the above are seen on the west side of the high road, where they strike parallel to the neighbouring granite-boundary, with a dip to the east. A specimen was examined from the little "sike" marked on the map [903]. Here the metamorphism seems more complete. Cyanite, colourless mica, and the green chloritoid substance are absent or rare, and the conversion of the last-named into dark mica is seen in various stages. Some of the mica is green, but most of it is brown with intense pleochroism. There are a few comparatively large flakes, and these enclose little prisms of apatite. The recrystallization of the groundmass is complete, but there is the same difficulty in determining to what extent quartz may enter into it as well as felspar. There is undoubted quartz in little veins following the general lamination of the rock as indicated by the mica-flakes. Iron ores are again rather abundant, and are of more than one kind.

The red highly-metamorphosed rock in contact with the granite in the little ravine behind Wasdale Head Farm is identical with those just described from the eastern margin of the intrusion. Magnetite and brown mica are tolerably abundant; cyanite is sparingly distributed; apatite occurs both in the larger mica-flakes and in the general groundmass, which consists as before of an aggregate of clear felspar in minute crystals [764].

The southern slope of Wasdale Pike is occupied by a succession of highly altered ashes, which, as already stated, we class with the Rhyolitic Group. They are faulted on the north side against the andesitic rocks, on the south against the Coniston Limestone group. They show plenty of dark mica, have a very distinct lamination, and give in the field a suggestion of crystalline schists or even gneisses. At some horizons the presence of fragments of the usual pink rhyolite gives the rocks the character of breccias. There is often some admixture of detrital material, chiefly indicated in the slides by angular clastic grains of quartz [1167]. The general features show only minor variations from the types just described. Recrystallized felspars, probably accompanied by quartz, make up the bulk of the rock; magnetite and brown mica are universally present; colourless mica, cyanite, and apatite occur more sparingly and occasionally. The original felspar crystals are always completely replaced by a mosaic of new felspar, and the little areas are often bordered by magnetite with some brown mica

[1168]. In one of the lowest rocks exposed the mica is clustered in little ovoid patches about $\frac{1}{10}$ inch in diameter [1132]. This is close to the granite.

These rocks differ from the other metamorphosed ashes, which we have classed as andesitic, not only in the presence of certain aluminous and other minerals, but in the smaller proportion of brown mica and the absence of the lime-bearing silicates, augite and hornblende. Only one of our specimens, from the uppermost bed exposed, shows green hornblende as well as brown mica. The two minerals are not mingled, but occur in alternate narrow bands, about twenty in an inch [763]. Possibly this rock originally contained some calcareous matter, as well as clastic grains.

The thin ash-beds associated with the rhyolite in the Coniston Limestone group have not been minutely examined, and it would probably be difficult to separate them, within the zone of greatest metamorphism, from the impure limestones. Near Wasdale Head Farm, however, a laminated white rock occurs between the Upper Limestone and the underlying rhyolite, which perhaps represents the flaky ash seen in a similar position in Blea Beck. In a section [1044] it is seen to be composed in great part of minute scales of colourless mica. These are collected in densely matted masses with a rough parallel orientation, and also occur in rather larger flakes associated with the usual brown pleochroic mica. In the same slide are seen very imperfectly separated crystals giving brilliant interference-tints and possibly referable to pyroxene (?).

Finally, it should be noticed that in ashes which had already suffered silicification the metamorphism seems to have been limited to the production of brown mica, which forms streaks and clusters of small flakes mostly surrounding grains of magnetite. Rocks of this type show no difference between specimens taken close to Wasdale Head Farm, among intensely metamorphosed beds [879], and others from a quarry on the high road nearly 800 yards from the granite-margin.

### C. *The Coniston Limestones.*

As exposed in Blea Beck plantation, in the grounds of the Hotel, the calcareous rocks show few signs of metamorphism. The purest beds, such as the highest seen at this locality, have a finely crystalline texture, and consist simply of a fine mosaic of calcite grains, with little or no foreign matter [871]. With other beds the case is different, and some are rather of the nature of calcareous shales with nodular bands of less impure rock. The matrix of the Calcareous Breccia is sometimes a tolerably pure limestone, which, like the preceding, has recrystallized to a calcite-mosaic, crowding the dusty impurities into particular patches [862]; but at other times there is much more non-calcareous material, which seems to be mostly of volcanic origin. The base of the breccia, indeed, may be described rather as a calcareous ash [870]. The fragments in the breccia are for the most part angular pieces of pink rhyolite, similar

to those in the volcanic breccias and perhaps of direct volcanic origin; but there are also fragments of decomposing andesite with vesicles filled with calcite, and rolled crystals of striated felspar [862]. Some of the lower beds exposed in the Upper Coniston Limestone division are more gritty in appearance, and one contains plenty of rounded quartz and fragments of spherulitic rhyolite, as well as ashy material [1077]. This bed is interposed between two flaky agglomeratic ashes, and the admixture of volcanic material with the detrital and calcareous is very clear. The Lower Coniston Limestone here offers no characters which call for notice.

Although the limestones in our district cannot be followed in continuous exposures from the unaltered to the highly altered state, we can obtain a general idea of the extent and progress of the metamorphism by comparing specimens from different spots. As already stated, the Blea Beck rocks are in general unaffected by any thermal metamorphism, but one or two specimens show the beginning of the change in the development of a few scraps of a pyroxenic mineral, evidently formed at the expense of part of the calcareous material. This is at 1400 yards from the granite [870]; (compare with [1077] from the same locality, which is quite unaltered). A specimen taken west of the small plantation near Wasdale Beck, about 1000 yards from the granite, shows more of the lime-silicate with less calcite [906]. This rock, like the preceding, is a calcareous ash, though it belongs to a lower horizon. We shall notice in its proper place a calcareous rock in the Silurians, which is well seen at Packhouse Hill, about 600 yards from the granite. There lime-silicates are abundantly present, and only a rare patch of the original calcite is to be seen [1225]. Finally, in the exposures of Coniston Limestone near Wasdale Head Farm, at distances of 300 yards and less from the contact, all trace of the original calcareous ingredient is merged in metamorphic products. The progressive modification thus indicated is more gradual than that recorded in Lossen's metamorphosed limestones around the granite of the Ramberg.

In the Wasdale Head section, as already stated, both Upper and Lower Limestones occur in a highly altered condition, the carbonic acid having been completely expelled with the production of various crystalline silicates, which are, naturally, minerals rich in lime. The Lower Limestone may be found, with some difficulty, in two small "sikes" west of the farm, and was discovered here by Profs. Harkness and Nicholson, who recognized it as a metamorphosed limestone containing idocrase. The Upper Limestone, though much better exposed, and close to the farm-road, seems to have escaped notice. It is to be observed that the uppermost and purest beds are not seen in this section, which shows only part of the Calcareous Breccia and a few feet of the overlying strata. The small part of the Lower Limestone that is accessible also seems not to belong to the most purely calcareous portion; and, indeed, in both limestones the presence of various aluminous silicates points to some original admixture of earthy or ashy material, as well as the possible intro-

duction of silica in connexion with the metamorphism. None of the altered calcareous strata can be followed for more than about fifty yards along their strike, and the exposures, which are all within 300 yards of the granite-boundary, show complete metamorphism in every case. The next appearance of the Calcareous Breccia towards Great Yarlside, about three-quarters of a mile from the granite, shows little or no alteration. As the limited nature of the exposures thus precludes any attempt to trace the gradual changes in particular beds, we shall content ourselves with describing the constitution of the chief types of metamorphosed limestones found in the sections mentioned.

Beginning with the representative of the Lower Limestone, the most interesting type to be noticed is that consisting mainly of idocrase with lime-garnets and other lime-bearing silicates. In hand-specimens the idocrase is often seen to compose the bulk of the rock, and is readily identified by its light-brown colour, rather imperfect cleavage, and resinous lustre. It forms a framework in which the garnets, &c. are embedded, and usually presents no crystal-outline, nor does it then show the concentric shell-structure found in many idocrases. The specific gravity of a typical specimen of the rock was found to be 3·476, which answers to idocrase with a smaller quantity of lime-garnet. In some parts of the rock the idocrase shows crystal-boundaries, viz. the prism (*m*), pyramid (*y*), and basal (*c*) *.

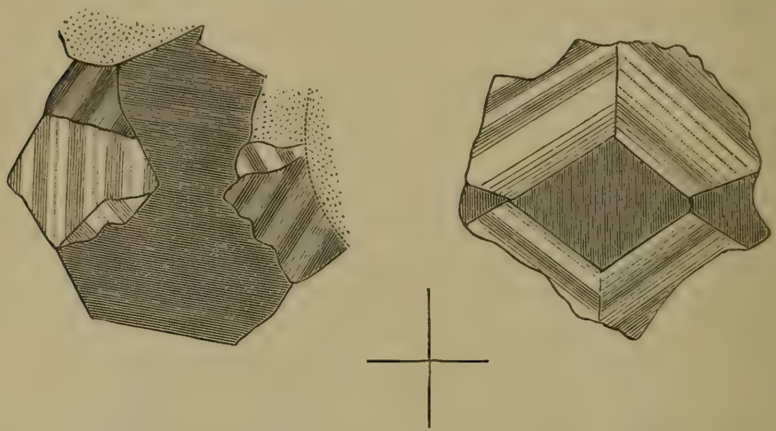
In thin sections the idocrase appears as large shapeless plates enclosing the garnets and other constituents in ophitic fashion, and, as is often the case in minerals having this mode of occurrence, the cleavage-cracks are not well developed (see Pl. XII. fig. 1). The mineral gives bright polarization-tints, which vary slightly in different parts of a crystal. Idocrase is usually stated to give very low tints: Rosenbusch says that the birefringence rarely exceeds ·0015; Michel-Lévy and Lacroix give ·0015 as the mean and, apparently, ·002 as the maximum. Prof. Brögger, however, found brightly polarizing idocrase in the metamorphosed calcareous rocks of the Christiania district, and a slice [1042] of the Monzoni idocrase shows the same character. The idocrase of our rock contains numerous inclusions, mostly minute granules of pyroxene (?), and sometimes crowds of little needle-shaped crystals which we have not identified [1169].

The garnets occur in dodecahedra, up to $\frac{1}{4}$ or sometimes $\frac{1}{2}$ inch in diameter, which are often isolated in the exposed outcrop of the rock, owing to weathering. The crystals have lustrous faces, with the somewhat greenish-yellow colour common in the lime-alumina-garnets (grossularite). In thin slices the mineral shows some interesting features. It is seen to be birefringent, and to present in

* Mr. W. M. Hutchings informs us that he has measured one of these crystals on the goniometer. He finds the angle between the basal plane (*c*) and the unit pyramid (*y*) to be between 37° and 38°. Miller gives, for idocrase, 37° 7'. Mr. Hutchings also states that the optical properties are those of normal idocrase.

each crystal a division into several distinct "fields" with different optical orientation. In addition to this there is a zonary banding in polarized light, owing to the successive concentric shells of the crystal differing in amount of double refraction. (See fig. 5.)

Fig. 5.—[1211]. *Doubly-refracting lime-garnets in the idocrase-garnet-rock, metamorphosed Lower Coniston Limestone, of Wasdale Head.*



Drawn in polarized light to show the polysynthetic structure and zonary banding. The + indicates the position of the crossed nicols. Included granules of pyroxene, &c. are omitted for the sake of distinctness.

The existence of optical anomalies in the garnets of the *Kalk-silicathornfelsen* has long been recognized. The property of double refraction seems to be constantly accompanied by polysynthetic twinning and a more or less pronounced zonary banding. Klein has distinguished four different types of structure in the doubly refracting garnets. Those of Wasdale Head belong, so far as our observations go, to his *Rhombendodekaëdertypus*, which is defined as built up by twelve hemimorphic rhombic pyramids, each having its base on a face of the rhombic dodecahedron and its apex at the centre of the crystal. The appearances actually seen in slices of the rock of course vary considerably, according to the direction in which each individual crystal chances to be cut. Rosenbusch * states that the type of structure in question is by much the most common in the doubly-refracting garnets, and gives an excellent figure in illustration of it. In our specimens the division between the several individuals of the polysynthetic twin is often rather irregular. The zonary banding is usually, but not always, well marked. None of the zones are isotropic, but the birefringence varies considerably from zone to zone and is negative in character. When strongest, it is about equal to that of quartz: only in rather thick slices do the interference-tints rise to the yellow of the first order. Doubly-refracting garnets, though not confined to metamorphosed limestones,

* 'Mikr. Physiogr. d. petrogr. wicht. Miner.' 2nd ed. (1885) p. 264, and pl. xiv. fig. 2.

appear from the accounts of different writers to be very characteristic of such rocks. Another British example is afforded by the Carboniferous calcareous shales in contact with the large dyke at Plas Newydd on the Menai Straits. The garnets at that locality have a zonary structure, and show the same type of polysynthetic grouping as those of the Wasdale Head rock [149].

In the most common type of the metamorphosed Lower Limestone, doubly-refracting garnet and idocrase build most of the mass. Among other minerals met with are pyroxenes similar to those to be described in the Upper Limestone. A colourless augite is the most common, and is evidently the same as that described below. It is sometimes abundant in crystalline patches showing augite-cleavage and even twinning [1207], and the minute granules, giving bright polarization-tints, which often crowd both garnet and idocrase are perhaps the same mineral. These little granules have the rounded or "globulitic" appearance which has been commented on by Prof. Brögger in similar rocks in Norway.

Another mineral not infrequently found is tremolite, which forms little veins and patches, and encloses imperfect crystals of light-brown sphene [1170]. Anorthite is sometimes to be identified. Quartz apparently does not occur, except in narrow veins evidently representing little cracks.

Another type met with in the altered Lower Limestone shows in hand-specimens a dull-white ground studded with round light-brown spots, up to about $\frac{1}{10}$ inch in diameter, and more irregular pinkish-brown patches of similar size. The round spots are garnets, which in slices are found to be isotropic, and the less regular patches are evidently imperfectly-separated crystals of the same mineral. Both contain a large amount of enclosed material similar to their matrix, which seems to be usually a very finely granular aggregate of wollastonite, augite, &c. [951]. It may be noted that these isotropic garnets are of a browner colour than the doubly-refracting ones (essonite); but there is no reason to suppose that the isotropic character is connected with chemical composition. The isotropic garnets are never in such perfect crystals as the others, and often seem to have been arrested in an incomplete state of development.

The metamorphosed representative of the Upper Limestone is a compact porcellanous-looking rock of pale bluish-grey or greenish-grey colour, closely comparable with lime-silicate hornstones from the Harz and other regions. On closer examination, it often shows a rather mottled appearance on a small scale, some parts being greenish and giving evident indication of crystalline structure. The lower beds, representing the Calcareous Breccia, enclose numerous angular, subangular, and rounded fragments similar to those seen in the unaltered strata in Blea Beck. Some of these fragments are of dark colour and dull appearance, but the majority have a grey horny aspect, and are at once recognized as the usual rhyolite-fragments of these beds, though they appear to have suffered some metamorphism, and their boundary against the enclosing matrix is not always perfectly sharp.

A common feature, which is also seen in the metamorphosed Lower Limestone, is the occurrence of little ovoid or irregular nests, a quarter of an inch to an inch in diameter, of little greenish or light brown crystals, which radiate not from the centre but from one end of the nest. These little aggregates, which consist of a monoclinic pyroxene mineral presumably an augite rich in lime, may perhaps represent original nodular patches more purely calcareous than the rest of the rock. The mineral seems to be identical with one already mentioned as an occasional constituent of the metamorphosed andesites. In the little nodules it is usually bordered by a zone of small felspar crystals (see Pl. XII. fig. 2).

The rhyolite fragments in the metamorphosed Calcareous Breccia appear, in some instances, to have been altered by silicification prior to the metamorphism, but others preserve the cryptocrystalline, microspherulitic, and other structures proper to them. Some are traversed by curving perlitic cracks, now occupied by minute veins of quartz or sometimes pyroxene. This latter appearance is beautifully shown in polarized light, and is clearly due to the cracks having been filled by minute calcite-veins, subsequently metamorphosed into a lime-silicate [1043].

Besides these fragments, there are often little round areas of clear quartz, sometimes consisting of an irregular mosaic. These correspond to the rolled grains of clastic origin seen in the non-metamorphosed rocks, but the quartz has apparently been recrystallized *in situ* [909 &c.].

The matrix in which the fragments are embedded is seen under the microscope to consist of a densely packed aggregate of various crystalline silicates, in which a few are sometimes developed in larger crystals, mostly of very imperfect outline and arranged in tuft-like groupings. The higher beds of the limestone have the same general character.

One common mineral is a colourless, brilliantly polarizing amphibole, which may be referred to tremolite. Cross-sections show the prismatic hornblende-cleavage, and longitudinal sections give extinction-angles up to about 16°. The transverse parting seen in the tremolite of some metamorphosed limestones, *e. g.* in Glen Tilt, Perthshire [1174], is not found here. The mineral sometimes occurs in vein-like streaks or fan-like tufts [909]; at other times it makes up almost the whole of the rock in particular spots [1215], see Pl. XII. fig. 3. The abundance of tremolite and other magnesian minerals in these altered rocks, sometimes to the exclusion of simply lime-bearing silicates like wollastonite, suggests that the limestone may have been partly dolomitized before its metamorphism.

Two pyroxene minerals are recognizable in the rock, often associated in the same slide, building little crystalline grains and minute granules. One of these, with a scarcely perceptible yellow tinge in the slices, has the augite-cleavage and gives in longitudinal sections a maximum extinction-angle of about 40°. Its other properties are those of the augites, and, being doubtless a variety rich in lime, it

may be termed "lime-augite." It is evidently the mineral which gives the greenish tint to hand-specimens of the rock, and is apparently identical with the pyroxene which occasionally occurs in the metamorphosed andesites. It is usually a conspicuous element in slices of the altered Upper Limestone and Calcareous Breccia (see Pl. XII. fig. 4).

The other pyroxene, completely colourless in the sections, has a considerably lower refractive index and rather less double refraction. Sections showing one marked set of cleavage-traces extinguish parallel to these traces. Taking account of all its properties, this mineral may be referred with some confidence to wollastonite. It is less abundant than the augite, and does not occur in larger crystals such as those in the radiating nests and tufts of the latter mineral. In some slides it is the dominant pyroxene [872], in others it occurs in smaller quantity associated with the augite [874].

We have not found garnet in the metamorphosed Upper Limestone. A mineral probably referable to idocrase (?) occurs in one or two slides [1217], but never in the abundance which characterizes the metamorphosed Lower Limestone. Felspar is a common constituent, in groups of irregular crystal-grains or occasionally in ophitic plates moulding the augite, &c. It has the water-clear appearance common to the authigenetic felspars of all these metamorphosed rocks, and the crystals are more commonly simple than twinned. Judging by extinction-angles observed in the twinned crystals, both acid and basic felspars occur: some are certainly to be referred to anorthite. Quartz seems to be present only sparingly in these rocks, but in the very fine-grained parts it is not easy to discriminate between this mineral and felspar, and the analysis given below proves that a certain amount of free silica is present. Some slides of the Calcareous Breccia contain a considerable amount of brown mica, usually in small flakes of a pale colour [1214, 1215, 1216], and there are some little veins of pale yellow pleochroic mica with clear quartz [1213]. A grain or two of magnetite is seen only very rarely [874].

It will be seen from the above brief account that the Wasdale Head section affords some interesting examples of highly-metamorphosed calcareous rocks. The beds here exposed have evidently not, for the most part, been of the nature of pure limestones. The considerable amount of alumina represented by the garnets and idocrase in the "Lower Coniston Limestone" at this locality clearly points to the former abundance of ashy material in the strata; they were probably calcareous shales or fine ashes, like those which are seen at Stile End and constitute the usual *facies* of this subdivision. The Upper Limestone, in so far as it is represented at this spot, must also have been impure, and was probably to some extent dolomitized. Indeed, Mr. Garwood finds these porcellanous-looking rocks to be rich in magnesia as well as in lime. The following analysis of an average specimen of the metamorphosed Upper Limestone probably gives a fair idea of the constitution of the altered rocks of this divi-

sion (I.). We give for comparison an analysis of a similar rock from the Christiania district (II.) :—

| | I. | II. |
|---|---|---|
| $SiO_2$ | 55·45 | 57·43 |
| $TiO_2$ and $ZrO_2$ | ... | 1·13 |
| X (unknown) | ... | 0·12 |
| $CO_2$ | 0·00 | 0·00 |
| $P_2O_5$ | ... | trace |
| Cl | ... | trace |
| $Al_2O_3$ | 15·91 | 17·53 |
| $Fe_2O_3$ | 6·84 | 0·00 |
| FeO | not estim. | 1·76 |
| MgO | 3·65 | 1·47 |
| SrO | ... | trace |
| CaO | 11·50 | 8·51 |
| $Na_2O$ | 0·10 | 1·76 |
| $K_2O$ | 3·36 | 8·51 |
| $Li_2O$ | ... | trace |
| $H_2O$ | ... | 1·05 |
| $FeS_2$ | ... | 0·77 |
| Ignition | ... | (1·30) |
| | 96·81 | 100·04 |
| Specific gravity | 2·712 | 2·741 |

I. Metamorphosed Upper Coniston Limestone, Wasdale Head Farm; anal. E. J. Garwood.

II. Pale violet *Kalkhornfels*, Gunildrud, near Christiania; anal. Jannasch, Nyt Mag. Naturvidensk. vol. xxx. p. 303.

The notable percentage of potash in our rock (though less than in the Norwegian one) must have come from ashy material in the original beds, and the alumina points to the same fact. The potash now exists in the abundant orthoclase of the rock: the percentage of alumina is evidently too high to be contained in the felspars alone; part of it must be combined in the pyroxene. A rough calculation shows that the amount of quartz in the rock must be about 19 per cent. If we suppose that the rock has undergone no change of total chemical composition beyond the loss of carbonic acid, and that the whole of the lime and magnesia originally existed in the form of carbonates, we find that silica must have formed about 50 per cent. of the original rock, or excluding the calcite and dolomite, 67 per cent. This figure does not seem too high, if, as we believe, the non-calcareous part of the rock was chiefly ashy material of rhyolitic character, with a little clastic quartz in addition. The analysis does not, therefore, prove that silica has been introduced during the metamorphism.

The phenomena of metamorphism exhibited by the Wasdale Head rocks agree in many particulars with those that have been described in impure calcareous strata near other intrusive masses, such as the Ramberg granite in the Harz *, and the hornblende-

* Lossen, 'Erläut. zur geol. Specialk. v. Preussen' (1882), Blatt Harzgerode, pp. 66–73.

granite of Eker and Sandsvär, near Christiania *. English geologists who have read the masterly memoirs of Lossen, Brögger, and Lang will be interested to learn that many of the phenomena described by the Continental petrologists may be studied in our own country. The metamorphism near the Shap Fell granite is as complete as any described in similar strata, the rocks being entirely reconstituted with expulsion of the whole of the carbonic acid.

### D. *The Silurian Rocks.*

Owing to a strike-fault, which has already been alluded to, the lowest members of the Silurian are not seen in our district. The next set of rocks to be noticed is the Lower Coniston Flags or Brathay Flags, which are well exposed, and can be traced to within about 350 yards of the granite. There is little doubt that these strata are in contact with the intrusive rock along its southern boundary, but this junction and the inner ring of the aureole of metamorphism are concealed by superficial accumulations. For this reason, and in view of the numerous descriptions of metamorphosed argillaceous rocks already given by various writers, it will not be necessary to treat the rocks in question at great length. We shall confine ourselves chiefly to following the stages of alteration exhibited by the rocks exposed along the banks of Wasdale Beck. As the line thus traversed coincides very closely with the strike of the beds, we need not expect to find any variations other than those due to varying degrees of metamorphism.

The exposure nearest to the Hotel is about 1400 yards from the granite outcrop as laid down on the map, and here the metamorphism is very slight. It consists in a certain hardening of the rocks and a partial loss of the fissile character, though both bedding and cleavage are still easily made out. The flags here have a dull black colour, due no doubt to organic material, and they contain recognizable graptolites. The specific gravity is 2·7645. A slice [863] from this locality shows abundance of carbonaceous matter, mainly arranged along the direction of lamination, which is crossed at an acute angle by cleavage. There are also minute angular grains of quartz. These constituents are embedded in a mass of finely-divided dusty matter, such as might arise from decomposed felspathic fragments, with a certain amount of quartz-cement. The specimen does not differ materially from the Brathay Flags of Stockdale [1284].

Following the rocks up the beck, we observe that from dark they become yellowish-grey in colour, but with countless little black spots which take on the lustre of mica. The spots are seen as far as the flags can be traced, that is, within about 350 yards of the granite. A specimen here has a specific gravity of 2·732, which is lower than that of the less altered rock.

A microscopic examination of the specimens shows that the outer

* Brögger, 'Die silurischen Etagen II. und III. im Kristianiagebiet' (1882); see also Lang, Nyt Mag. Naturvidensk. vol. xxx. pp. 335 *et seqq.*

limit of the aureole of mineralogical metamorphism is rather sharply defined. While the flags seen nearest the Hotel have undergone no important alteration, specimens at no great distance from them, and about 1220 yards from the granite-boundary, show very considerable modifications. The carbonaceous matter has been entirely dissipated by "ignition," unless indeed it be partly represented by some of the black granules scattered through the rock. We cannot be sure that some of these are not graphite, and the flaky form of many of them renders it probable; but others are certainly magnetite, and by their tendency to crystal outline suggest a metamorphic origin. The chief authigenetic mineral, however, is brown mica, which is disseminated in minute flakes throughout the whole mass of the rock. The character of the ground, showing very minute granules of quartz and apparently felspar, is more evident; but this may be due rather to the removal of the opaque organic matter than to any real change in the other constituents. The more easily visible angular grains of clastic quartz, at least, have remained unaltered [1221].

Nearer to the granite (at 870 yards) the brown mica forms flakes slightly larger and more distinct, while the general ground of the rock gives clear evidence of recrystallization. In the little streaks where this is best seen, there is a fine-grained aggregate of grains which may include felspar as well as quartz, and the authigenetic character of this aggregate is sufficiently proved by its mosaic arrangement, its limpid appearance, and especially the manner in which it moulds and encloses the mica. In other parts of the slide the nature of the very fine-grained mass, obscured by the mica, is not to be made out with certainty [1220]. There are still evident angular quartz-grains of detrital origin. The opaque grains belong to a yellow pyrites-mineral which seems to be pyrrhotite.

[We are indebted to the kindness of Mr. W. Maynard Hutchings for drawing our attention to the occurrence of anatase in a specimen from Wasdale Beck. The mineral occurs in groups of very minute crystals in the clearer spaces of the rock, and is conspicuous under a high power by its very high refractive index and birefringence [1327]. Owing probably to the total-reflection border, the crystal form is seen in only a few of the crystals. It appears to be the simple pyramid, or but slightly modified. The straight extinction and the character of the double refraction ($\omega > \epsilon$) agree with anatase, and there is but little doubt of the identity of the mineral. Further, it seems to be formed at the expense of rutile, for Mr. Hutchings points out that the "clayslate-needles," which he finds in the less metamorphosed flags lower down the beck, are here almost absent. The locality of the specimen is apparently about 800 or 900 yards from the granite-outcrop.—March 11th, 1891.]

Still approaching the granite, we come on to the spotted or "knotted" rocks. A specimen taken at 500 yards from the contact does not materially differ, except as to the spots, from the last, the recrystallized mosaic, in which some rectangular sections clearly point to felspar, being visible only in some portions of the slide, while the

rest is very obscure. The rather irregular spots, $\frac{1}{50}$ to $\frac{1}{20}$ inch in diameter, are differentiated by their comparative freedom from mica [1219].

At 360 yards from the granite the spots are more regularly ovoid and their boundary more sharply defined, the brown mica in the interspaces forming distinct small flakes arranged tangentially to the outlines. The central part of each spot contains smaller flakes, often rather rounded, but the marginal zone is free from mica [1218]. (See Pl. XII. fig. 5). In some specimens from this neighbourhood the mica in the general body of the rock has a marked parallel arrangement, which corresponds to the lamination of the original flags [864].

An example from Packhouse Hill has less mica, and that of a pale colour, but here pyrrhotite is exceptionally plentiful, and has presumably used up most of the iron which has elsewhere gone into the usual brown pleochroic mica [1222]. This is at 600 yards from the granite. A specimen from Collyrag Quarry, a hundred yards nearer, shows similar characters [1079]. These rocks are on a slightly higher horizon than the preceding. They show little or no indication of "spots," have rather abundant clastic quartz, and present a considerable resemblance to the Upper Coldwell beds exposed farther south.

The normal brown mica of the metamorphosed flags resembles in general characters that which has been produced in the andesitic and other rocks described above. Such mica has a special quality as seen in reflected light, which gives a peculiar purplish-brown sheen to the rocks in which it is abundant. With this goes a very intense pleochroism in thin sections, the absorption being almost complete for vibrations parallel to the cleavage-traces, while, if the nicol be turned a very little away from this position, a distinctly greenish-brown colour is seen. Similar characters have been described by various writers in the mica of "contact" rocks in other districts, and it would be interesting to ascertain whether the mineral is chemically different from the brown micas of igneous rocks. The only investigation we can find on this point is in Lang's brilliant paper on the Christiania district, already referred to above. He and Jannasch separated and carefully analysed the brown mica of a *Glimmerhornfels* in that district. They found it to contain 7·98 per cent. of magnesia and 21·94 of ferrous oxide, ferric oxide being entirely absent: also titanic acid occurs to the extent of 3·40 per cent *. Except for the absence of ferric oxide the figures differ but little from Schläpfer's analysis of the biotite of Miask. The last-named author has shown that the earlier analyses of micas leave much to be desired in point of accuracy.

The nature of the "spots" in such rocks as these is not an easy question, and it seems clear from the literature of the subject that the phenomena of spotted and knotted slate-rocks arise in several different ways. We find nothing of the local accumulation of the "pigment" of the rock into spots, which characterizes the

* *Op. cit.* p. 318.

outer ring of metamorphism (*Knotenthonschiefer*) in some districts of argillaceous strata, such as Rosenbusch's * *Steiger Schiefer*. The spots in our rocks are comparatively free from coloured constituents, and do not make their appearance until after considerable development of secondary minerals. The original pigment of organic matter is dissipated as the first result of metamorphism. Moreover, the spots in the Brathay Flags, when best developed, show a distinctly crystalline structure between crossed nicols, being evidently imperfect crystals charged with a large quantity of foreign inclusions. The ovoid form seems to be that of imperfectly formed crystals, for the general ground of each spot extinguishes parallel to the long axis of the irregular oval, which has no universal direction, but lies quite at random. Possibly the mineral may be andalusite.

Apart from the spots, it will be noticed that andalusite is absent, as well as other characteristic aluminous "contact-minerals." It would appear that the rock contained sufficient alkalies to build up a large part of the alumina present into secondary felspars.

The veins of white mica have already been mentioned. The rock adjacent to these shows some curious modifications, being built in great measure of a clear colourless mica similar to that occupying the veins [949, 1080]. This mica is partly in minutely-matted aggregates, but mostly in well-defined flakes with rough parallelism, moulded by a clear crystalline mass of grains, some of which show felspar-twinning. The brilliantly polarizing flakes are also moulded by another micaceous-looking mineral with a very pale greenish-grey colour and feeble dichroism, but not sensibly birefringent. This may be one of the ripidolite group, but we have not established its identity with any described variety. A little magnetite and granules of the supposed pyrrhotite occur. Brown mica is only sparingly associated with the white in this marginal modification of the rock. At about an inch from the actual vein, however, the spotted character of the rock is apparent, and brown mica occurs as usual in the interspaces between the spots. There is still a considerable amount of white mica, mostly in exceedingly minute scales within the spots, but partly in more conspicuous flakes near their margin. One slide [949] shows a crack running at right angles to the main vein, its course marked by a slightly coarser aggregate of colourless mica and quartz, with some clear felspar, a little of the ripidolite-like mineral, and occasional grains of yellow-brown tourmaline, touched here and there with blue.

Of the remaining members of the Silurian formation we have made no systematic examination, but the few specimens studied offer some points worth recording. The Upper Coldwell beds and the less calcareous portion of the Middle Coldwell, viz. the lowest strata of that division exposed at Packhouse Hill, bear a general resemblance to the uppermost beds of the Brathay Flags at the same locality, and the resemblance is borne out by the microscope. Numerous minute shreds of a mineral like tremolite disseminated through these metamorphosed flags perhaps point to a certain

* 'Abh. zur geol. Specialk. v. Elsass-Lothr.' vol. i. (1877) part 2.

amount of carbonates of lime and magnesia in the original rock. The metamorphism is evidently incomplete, and the clastic grains of quartz show no change.

The Coniston Grit and the Lower Coldwell beds (or grits in the Coniston Flags) resemble one another very closely. They are ordinary grauwacke grits. A specimen of the former, taken near Stakeley Folds, shows in a section subangular grains of quartz and felspar with some interstitial dusty matter like kaolin, and little patches of finely granular calcite. The felspar has minute twin-lamellation and is rather abundant, though subordinate to the quartz. There is no other clastic element except very rarely a flake of white mica. The rock is freely veined with quartz [1165].

For comparison we take a specimen of the Lower Coldwell grit at Packhouse Hill, about 600 yards from the granite-contact. The contrast is evident in hand-specimens, the metamorphosed rock showing the vitreous appearance of a quartzite, in which the granular structure is only faintly discerned. Under the microscope [1223] we see a mosaic of quartz and felspar, the irregular grains of which show the "sutural" junction characteristic of crystallization *in situ*. It is not easy to judge of the proportion of felspar present, since the grains are all perfectly clear, and twinning is rarely seen. The twinning is never compound, and the grains showing it give rather lower polarization-colours than the average, which seems to point to orthoclase. Besides these minerals there are numerous little rounded brightly-polarizing granules, colourless or very faint yellow, and precisely similar to those so commonly seen in the metamorphosed Coniston Limestones. We regard these as a lime-augite. The granules are aggregated together, especially in irregular vein-like streaks. The slide shows also some small irregularly-shaped granular patches, so densely packed as to be opaque, and appearing yellow in reflected light. These are, at least in part, of the same pyroxenic mineral, which corresponds closely in its distribution with the calcareous decomposition-product in the non-metamorphosed grit. It is noteworthy that neither mica nor garnet has been found. The kaolin seems to have gone with the carbonates to form pyroxene. (See Pl. XII. fig. 6.)

The quartz in this rock encloses many irregularly-grouped minute cavities, round or more frequently shapeless, with bubbles of various relative size. Judging by the apparent relief of cavities and bubbles, both glass- and fluid-pores may be represented, but no movement was verified in any of the bubbles.

The calcareous Middle Coldwell beds, as seen on the top of Packhouse Hill, exhibit a high degree of metamorphism. As in the Coniston Limestone, this is shown especially by the development of lime-bearing silicates, and, although we have no analyses of these Silurian strata, a comparison with the general character of the unaltered beds makes it appear that a very moderate proportion of calcareous matter, which would not cause a field-geologist to describe the rocks as limestones, is sufficient to make the metamorphism follow this line.

Probably more than one lime-silicate is present. The dominant one gives the interference-colours of a pyroxene, and has marked cleavage-traces, parallel to which it extinguishes. This may be referred with some doubt to wollastonite. It is partly collected in crystalline patches and streaks, but smaller granules of the same or a similar mineral make up a large part of the rock, in conjunction with a clear substance polarizing in grey tints and occasionally showing the twinning of felspar. In the pyroxenic patches occur grains of a yellow opaque mineral, probably pyrrhotite. Here and there among the pyroxene is seen a little grain of calcite, showing that here, at 600 yards from the granite, the elimination of the carbonic acid is not quite complete [1225].

In hand-specimens this rock has a compact homogeneous appearance, with a pinkish-grey or pale violet colour, and a hardness rather less than that of orthoclase. The specific gravity of an average specimen is 2·874, which agrees with the identification of the chief constituent as wollastonite. The pale violet colour figures frequently in descriptions of foreign lime-silicate rocks.

Specimens of the Middle Coldwells taken at a point S.S.W. of Wasdale Old Bridge show a similar compact porcellanous appearance, but with a light grey colour, They resemble very closely the Upper Coniston Limestone of Wasdale Head, but have a rather higher density, 2·899, owing, as the microscope shows, to a larger proportion of pyroxene. The dominant mineral here is the colourless lime-augite, which is largely developed, in crystal-plates enclosing the felspar, &c. in ophitic fashion [1306, 1307]. At this locality, about 460 yards from the probable outcrop of the granite, there is no longer any trace of calcite remaining. It would appear that, in these impure calcareous rocks, the particular lime-silicates produced vary from point to point, as determined, perhaps, by comparatively slight differences in the chemical composition of the mass. Some light is thrown on the conditions governing the formation of augite, wollastonite, &c., by Vogt's * interesting researches on slags.

An interesting feature in the Packhouse Hill section is a metamorphosed fault-breccia, which intervenes between the Lower and Middle Coldwell beds. The lowest beds seen here in the Middle division are ordinary flags, but there appears to have been a lower calcareous band similar to that described above, for fragments of the characteristic pale-violet rock occur in the breccia, mingled with pieces of the dark flags and vitrified-looking fragments of the underlying grit. The whole is united by a greenish finely-crystalline cement of pyroxene.

The fragments of grit appear in sections as a mosaic of clear crystal-grains of quartz and felspar, evidently of metamorphic formation. It is impossible to estimate the proportions of the two minerals, but a fair number of the grains show twinning and seem from their properties to be orthoclase. No repeated twinning is observed [1286, 1287]. Among the grains of the mosaic, and

* Arch. f. Math. og Naturvidensk. vol. xiii. (1890) pp. 34–71, Christiania.

enclosed by them, are patches of rounded granules, highly refringent and birefringent, which must be referred to a pyroxene, probably the lime-augite already frequently alluded to. These granules are mainly collected at the margin of the fragments or in the neighbourhood of little vein-like cracks.

The angular pieces of flag show a marked lamination defined by streaks of opaque dust. Their metamorphism is similar to that of the corresponding rocks *in situ*, except where the fragments are traversed by cracks and veinlets, which evidently represent a permeation by carbonate of lime and other substances. In these places a number of special minerals may be detected, lime-silicates predominating. The usual colourless augite is abundant in irregular crystalline patches, often accompanied by clear felspar and probably quartz. There are also streaks composed entirely of a minutely matted aggregate of rather fibrous tremolite [1285]. Near these there is frequently a pale yellow-brown pleochroic mica, in clusters of small flakes. A pyrites mineral occurs among the tremolite and felspar, and by its colour would be assigned to pyrrhotite.

The metamorphosed fragments of the more calcareous flags in the breccia generally show a finely granular mass, mostly polarizing in bright tints, but too minute to be precisely determined. The general character of the mass may, however, be inferred from those constituents which are here and there developed in larger crystalline patches. Of these the most usual is colourless augite, readily identified by its cleavage, extinction-angles, and interference-colours. Another conspicuous mineral is light brown, pleochroic sphene, which occurs plentifully in grains and good crystals (habit, $n$, $c$, $y$) scattered through the fragments.

The cementing material of the breccia is almost exclusively colourless augite, building a relatively coarse-grained crystalline aggregate, and enclosing plenty of little sphene crystals [1286]. This cement makes up on the whole a small part of the mass, and it, with the smaller veins traversing the fragments, clearly represents a calcareous infiltration filling the interstices of the original fault-breccia. No calcite now remains.

In conclusion we may note one or two points with reference to the metamorphism of the Shap Fell rocks as a whole. The production of new minerals is confined to distances of not much more than 1200 or 1300 yards from the granite-contact, or about equal to the mean semidiameter of the intrusive mass itself as exposed at the surface. The width of the metamorphic aureole, as thus defined, seems to be tolerably uniform in different directions from the granite. Moreover, this extreme limit of metamorphic action is very nearly the same, whether we consider the andesitic rocks, the rhyolitic ashes, the various calcareous strata, or the Brathay Flags.

Within the metamorphic aureole the changes increase in degree

as we approach the granite, and, with few exceptions, the rocks in the vicinity of the contact have been completely reconstituted. Our results, however, lead to the conclusion that any division of the aureole into distinct rings or zones would be arbitrary and artificial, and certainly could not be made to apply alike to the various kinds of rocks metamorphosed. In the andesites, for example, the transition from the least altered to the most altered types is so gradual that no lines of division can be drawn either in the field or by minute examination. In the rhyolitic ashes our descriptions show two different types, but the distinction of these two would probably resolve itself into one of degree rather than of kind, if it were possible to examine the rocks between 300 and 600 yards from the granite, between which limits we have found no exposures. As to the calcareous beds, these have been described in other districts as showing a very complete alteration to points even beyond the limit of the aureole in the associated slates, though with no gradations in metamorphism within those limits. But, although we find in our calcareous rocks a high degree of metamorphism extending to a considerable distance from the actual contact, this seems, so far as we can judge from the rocks exposed, to die away gradually to the boundary of the aureole. The flags in the Shap district are not well enough exposed to warrant any sweeping conclusions, but it would be difficult to draw any divisional line in those seen within the metamorphic region. Zones of metamorphism may perhaps be usefully laid down in certain cases, as, for instance, when a mineral like chiastolite is developed in the outer part of the aureole and disappears in the inner; but such divisions do not appear practicable in the Shap Fell district.

It is noticeable that the chemical effects of the metamorphism were first produced in those constituents of the rock which owed their origin to weathering, decomposition, &c., such as delessite, calcite, and carbonaceous matter. In other words, the substances which had been formed under normal atmospheric conditions were the least stable when subjected to the high temperature which accompanied the intrusion of the granite. The minerals of direct igneous origin in the volcanic rocks were less susceptible to thermal metamorphism, and the original quartz-sand in the flags proved especially refractory.

The several minerals detected in the various metamorphosed rocks as products of the metamorphism are summarized in the table given below. The absence or rarity of some characteristic "contact-minerals" of other districts is rather striking. Some of these are products which probably require special "mineralizing agents" to co-operate in their manufacture; such as fluorite, tourmaline, lithionite, and axinite; but the almost complete absence of andalusite, staurolite, and garnets (other than lime-garnets) is more remarkable.

In the table the occurrence of the minerals in the different rocks studied is marked by an asterisk (*). Parentheses ( ) indicate rarity or occurrence only under special conditions, *e.g.* in the vicinity

of veins. A query (?) indicates some doubt as to the identity of the mineral. The more doubtful ones, such as the possible andalusite in the spotted flags, are omitted altogether: as are also minerals, like epidote, of which the metamorphic origin is not satisfactorily established.

*Table showing the distribution of Minerals of Metamorphic Origin in the chief rocks examined.*

| Minerals. | Andesites. | Andesitic Ashes. | Rhyolites. | Rhyolitic Ashes. | Lower Limestone. | Upper Limestone. | Brathay Flags. | Mid. Coldwell beds and Fault-Breccia. |
|---|---|---|---|---|---|---|---|---|
| Quartz | * | * | * | * | ... | * | * | * |
| Orthoclase | * | * | * | * | ... | | ? | * |
| Plagioclase (various) | * | * | * | * | * | | * | * |
| Colourless Mica (Muscovite) | ... | ... | * | * | ... | ... | * | ... |
| Brown Mica (probably near Biotite) | * | * | * | * | ... | * | * | * |
| Ripidolite? | ... | ... | ... | ... | ... | ... | * | ... |
| Green Hornblende | * | * | ... | (*) | ... | ... | ... | ... |
| Actinolite | * | * | ... | ... | ... | ... | ... | ... |
| Tremolite | ... | ... | ... | ... | * | * | ... | * |
| Colourless Augite (probably rich in lime) | * | * | ... | (?) | * | * | ... | * |
| Wollastonite | ... | ... | ... | ... | * | * | ... | * |
| Idocrase | ... | ... | ... | ... | * | ? | ... | ... |
| Grossularite (birefringent) | (*) | ... | ... | ... | * | ... | ... | ... |
| Essonite (isotropic) | ... | ... | ... | ... | * | ... | ... | ... |
| Common Garnet | (?) | ... | ... | ... | ... | ... | (?) | ... |
| Tourmaline | ... | ... | (*) | ... | ... | ... | (*) | ... |
| Sphene | * | ... | ... | ... | * | ... | ... | * |
| Rutile | ... | ... | ... | * | ... | ... | ... | ... |
| Anatase | ... | ... | ... | ... | ... | ... | * | ... |
| Apatite | (*) | ... | ... | * | ... | ... | ... | ... |
| Cyanite | ... | ... | ... | * | ... | ... | ... | ... |
| Magnetite | * | * | ... | * | ... | (*) | * | ... |
| Ilmenite | ... | ... | ... | * | ... | ... | ... | ... |
| Pyrites and Pyrrhotite | * | ... | * | (*) | ... | ... | * | * |
| Graphite | ... | ... | ... | ... | ... | ... | ? | ... |

## EXPLANATION OF PLATES X., XI., & XII.

### Plate X.

Map illustrating the relations of the Shap Granite and associated rocks.

(*The figures are all drawn in natural light, and, except* Pl. XII. fig. 5, *are magnified* 20 *diameters. The numbers in brackets* [ ] *refer to the slides.*)

### Plate XI.

Fig. 1 [902]. Shap Fell granite, normal type; showing clear quartz, turbid felspar, and flakes of brown mica. A flake near the lower right-hand edge contains a small zircon surrounded by a strongly pleochroic border.

Fig. 2 [399]. Dark patch in Shap Fell granite; showing quartz, felspar, and mica, as before, but the last more plentiful; also grains of sphene, octahedra of magnetite, and little needles of apatite. See p. 281.

Fig. 3 [1281]. Special modification of Shap Fell granite, containing andalusite; not found in place. The portion of the slide figured is rich in andalusite, which forms imperfect prismatic crystals, coated with brown mica and enclosing magnetite, zircon, mica, &c. Around some of the inclusions, especially zircons, are pleochroic halos, changing from bright yellow to colourless. The bulk of the rock is a mosaic of felspar and quartz with abundant crystals of magnetite and occasional apatite. See p. 283.

Fig. 4 [1205]. Metamorphosed vesicular andesite, near Wasdale Pike, about 800 yards from the granite. The upper half shows a vein of chalcedony converted into quartz. The lower half shows a vesicle in which the delessite (represented dark for distinctness) has been partly replaced by green hornblende. The clear mineral in the lower part of the vesicle is quartz. This rock represents an early stage of metamorphism. See p. 294.

Fig. 5 [897]. Metamorphosed vesicular andesite, Wasdale Pike, about 500 yards from the granite; showing the groundmass of the rock converted into a fine-grained aggregate of brown mica, felspar, quartz, and magnetite. Within the vesicle is green hornblende instead of mica. A patch of granular sphene is seen at the lower edge of the figure, on the line of a small crack. See p. 296.

Fig. 6 [1203]. Metamorphosed vesicular andesite, north of Wasdale Pike, about 400 yards from the granite; showing an unusual type of alteration, brown mica and felspar (in relatively large crystals) being formed in the interior of the vesicles, as well as in the groundmass. See p. 297.

### Plate XII.

Fig. 1 [1169]. Idocrase-garnet-rock in the metamorphosed Lower Coniston Limestone, Wasdale Head, about 100 yards from the granite; showing dodecahedra of grossularite garnet embedded in ophitic crystals of idocrase. Both minerals contain granular pyroxene and other matter, and the idocrase encloses groups of small needle-like crystals. See p. 311.

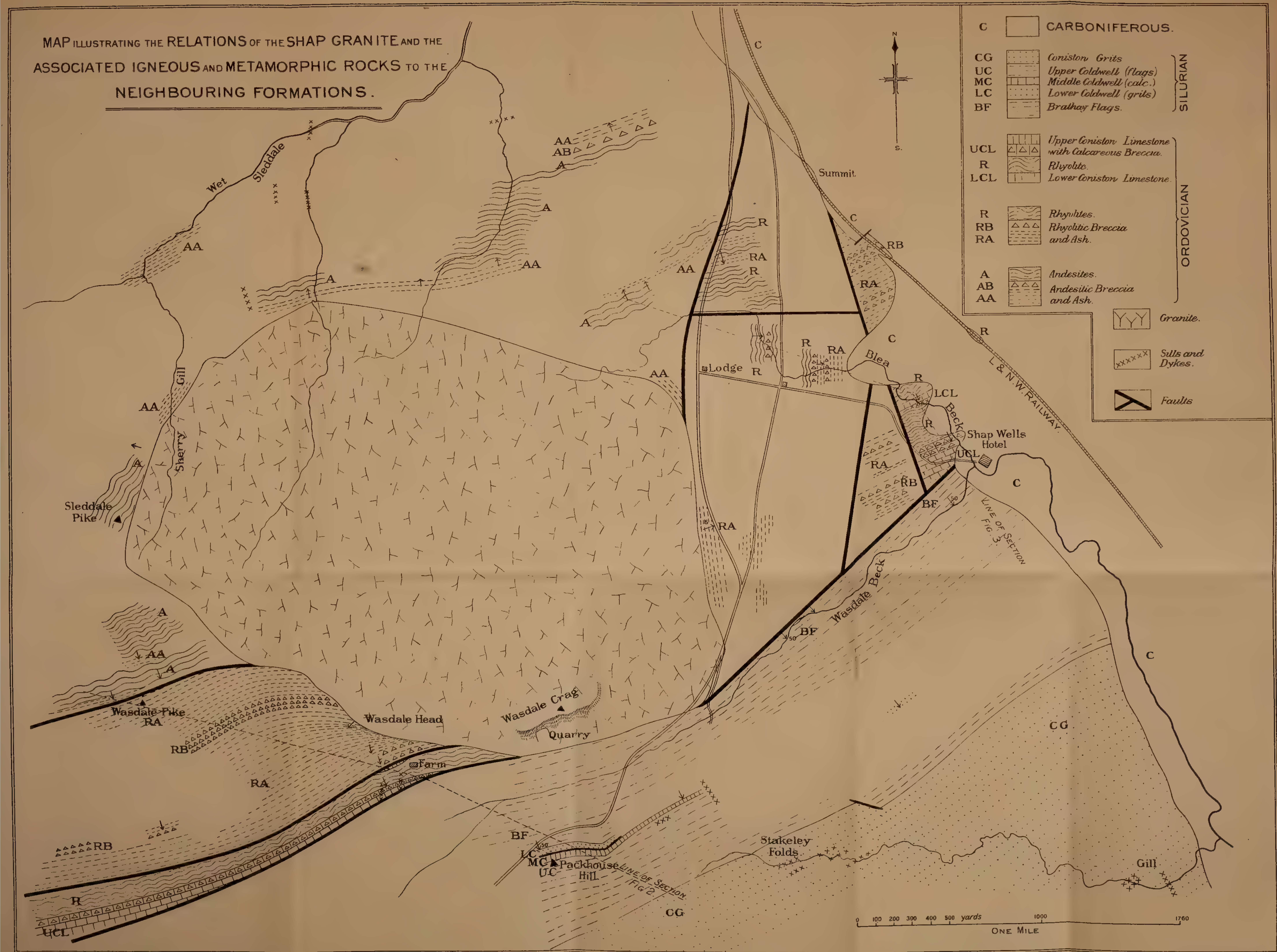
Fig. 2 [909]. Ovoid nest of colourless lime-augite, bordered by a zone of felspar crystals, in the metamorphosed Calcareous Breccia of the Upper Coniston Limestone, Wasdale Head, about 250 yards from the granite. Two quartz grains, of clastic origin, are seen in the lower part of the figure. Flakes of brown mica cluster round these and round the augite-felspar nest. See p. 314.

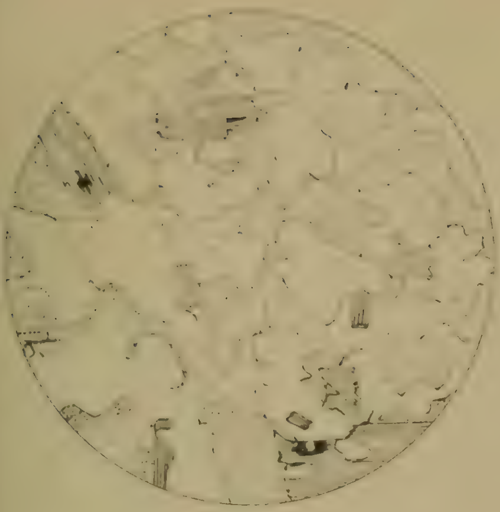
Fig. 3 [1215]. Tremolite-rock in the metamorphosed Calcareous Breccia at the same locality. See p. 314.

RBONIFEROUS.

*ston Grits*
*r Coldwell (flags)*
*lle Coldwell (calc.)*
*er Coldwell (grits)*
*hay Flags.*

SILURIAN


MAP ILLUSTRATING THE RELATIONS OF THE SHAP GRANITE AND THE ASSOCIATED IGNEOUS AND METAMORPHIC ROCKS TO THE NEIGHBOURING FORMATIONS.
C CARBONIFEROUS.
CG Coniston Grits
UC Upper Coldwell (flags)
MC Middle Coldwell (calc.)
LC Lower Coldwell (grits)
BF Bralhay Flags.
SILURIAN
UCL Upper Coniston Limestone with Calcareous Breccia.
R Rhyolite.
LCL Lower Coniston Limestone.
R Rhyolites.
RB Rhyolitic Breccia
RA and Ash.
A Andesites.
AB Andesitic Breccia
AA and Ash.
ORDOVICIAN
Granite.
Sills and Dykes.
Faults
N
S.
Wet Sleddale
Summit.
L. & N.W. RAILWAY
Lodge
Blea Beck
Shap Wells Hotel
Sherry Gill
Sleddale Pike
Wasdale Pike
Wasdale Head
Wasdale Crag
Quarry
Farm
Wasdale Beck
LINE OF SECTION FIG. 3.
Packhouse Hill
LINE OF SECTION FIG. 2
Stakeley Folds
Gill
0 100 200 300 400 500 yards 1000 1760
ONE MILE



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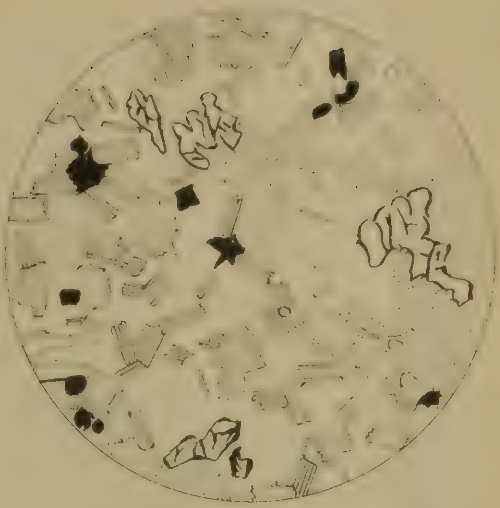

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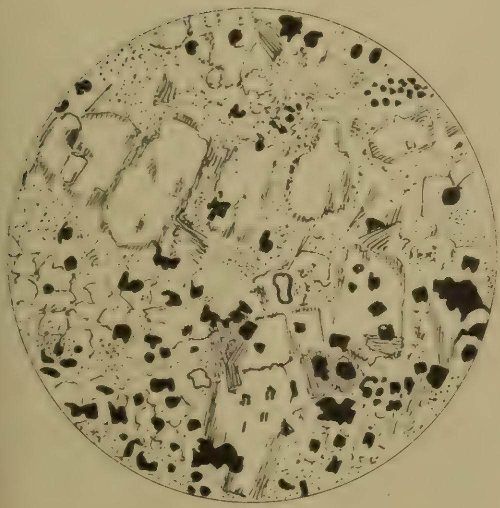

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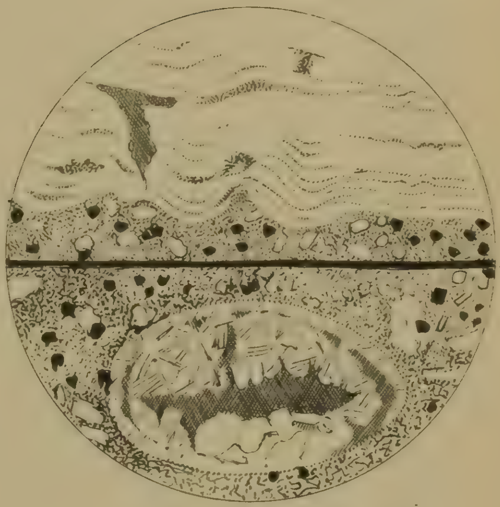

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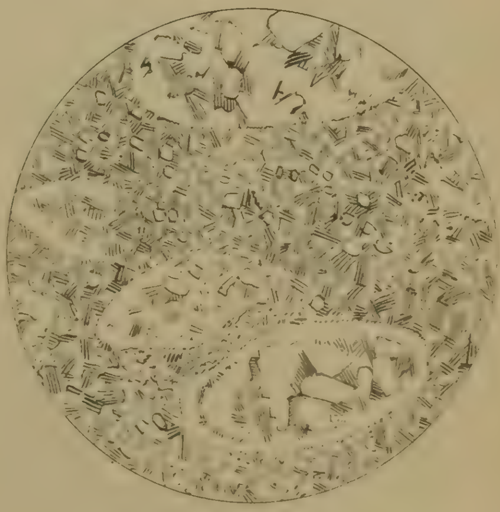
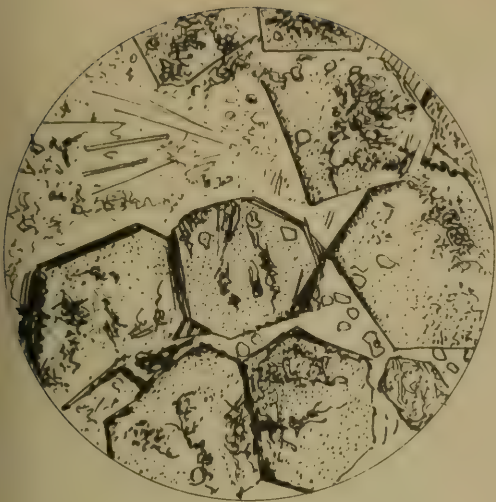


6.

Mintern Bros. lith.

SECTIONS OF SHAP GRANITE AND METAMORPHOSED ANDESITES



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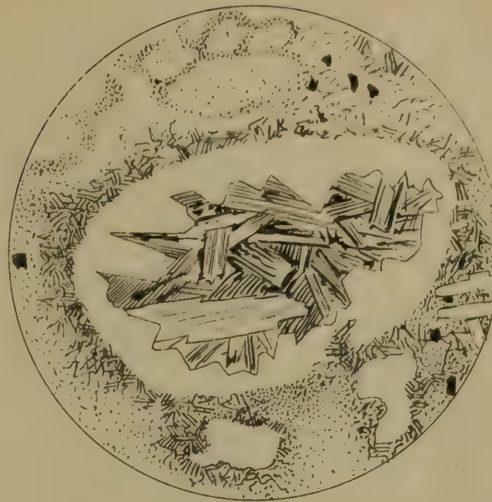

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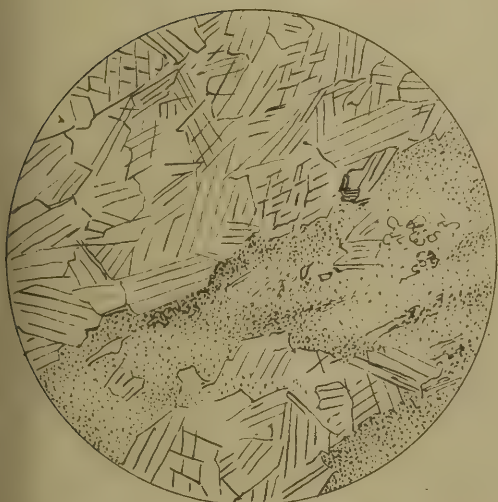

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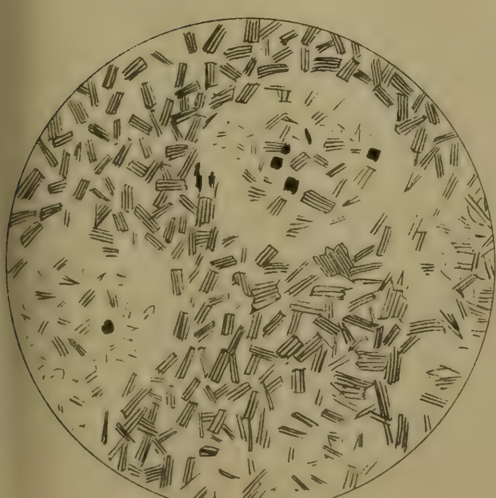

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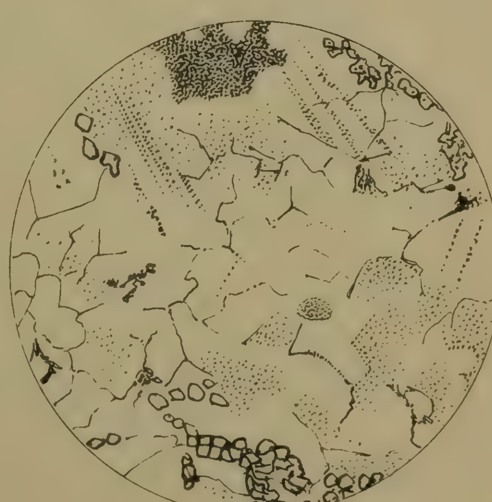

6.

A. Harker del. Mintern Bros. lith.

SECTIONS OF METAMORPHOSED ROCKS NEAR THE SHAP GRANITE

Fig. 4 [873]. Lime-augite-rock in the metamorphosed Upper Coniston Limestone at the same locality; showing colourless augite, both in crystalline aggregates with good cleavage and in granules and granular patches. See pp. 314–315.

Fig. 5 [1218]. Spotted schist in the metamorphosed Brathay Flags, north of Wasdale Beck, about 360 yards from the granite; showing little spots comparatively free from the secondary brown mica. This figure is magnified 100 diameters. See p. 319.

Fig. 6 [1223]. Quartzite, with colourless lime-augite, in the metamorphosed Lower Coldwell beds (grits) just north of Packhouse Hill, about 580 yards from the granite. The pyroxene occurs in distinct rounded granules and in finely granular patches. See p. 321.

## Discussion.

Prof. Bonney said that it was almost impossible to discuss a paper of such wide bearings, but it appeared to him to be one of great value. The most important points were the clear demonstration of the occurrence of felspar as a product of contact-metamorphism, and the effects of the intrusion of an igneous mass on pyroclastic rocks. He mentioned some cases which illustrated the uncertainty as to what mineral might be produced by contact-metamorphism.

Prof. Le Neve Foster said that the point which struck him as a miner, with reference to the intrusive boss of granite, was the absence of tin-ore. The Authors had remarked that no axinite or fluorspar had been found, and that tourmaline was very rare. It was interesting to note that where there was a lack of minerals containing boron and fluorine there was a complete absence of cassiterite.

Mr. Strahan asked for an explanation of the connexion referred to between the intrusion of the granite and the Pennine movements, by which were usually meant post-Carboniferous movements. The map exhibited of a necessity showed the dykes in a diagrammatic form. He enquired if this radial arrangement with reference to the granite would appear if they were shown on a true scale. In the Cautley neighbourhood micro-granites of the same age as the Shap granite occurred as sills in Coniston Limestone, and were cut across by mica-trap dykes, which seemed to show that the more basic rock was later than the more acid, and not earlier as argued from inclusions in the Shap granite.

Mr. Rutley thought that the red felstone-like dykes (often more or less micaceous) were probably apophyses of the Shap granite, as indicated by the Authors. With regard to the dark micaceous dykes being in any way related to the highly micaceous inclusions met with in the granite, he felt considerable doubt. Judging from the alterations produced artificially in rhyolitic rocks by heat, he was inclined to believe that the temperature under which the alterations in the rhyolites had been effected in the Shap area was a comparatively low one. The occurrence of the peculiar polysynthetic structure in the garnets which the Authors described was, he believed, the first notice of such a structure in British garnets, since, hitherto, it had only been observed in ouwarowite and in the

garnets of one or two localities in Saxony. The paper appeared to be one of exceptional interest and value.

Mr. BARROW was much interested in the Authors' list of minerals developed by contact-metamorphism. The light they had thrown on the origin of cyanite was particularly valuable to geologists working in the Central Highlands, where cyanite schist occurs on a large scale. In one instance a broad belt of this schist follows the outcrop of an igneous gneiss for some miles in such a manner as to suggest contact-metamorphism. The crystals of cyanite show little or no signs of deformation, and if developed by contact-metamorphism seem to point to the conclusion that the igneous rock originally consolidated as a gneiss.

Mr. MARR, in reply, recapitulated the reasons which had caused the Authors to connect granite, felsites, and mica-traps alike with the existence of a deep-seated magma, without asserting which portions of this were first consolidated. The movements in the Pennine Chain to which they had referred were those pre-Carboniferous ones which affected only the Lower Palæozoic rocks. Though the map of dykes exhibited was necessarily diagrammatic, the directions of those dykes which they had not themselves examined were taken from the published maps of the Geological Survey.

He believed that the metamorphism produced by the granite might throw some light upon the changes which had occurred in the rocks of a "regionally metamorphosed" area. The Authors had attempted to show that the Shap-granite intrusion was connected with earth-movements. If such movements had taken place to a greater extent, dynamic metamorphism would doubtless have altered the granite, the dykes, and the various sedimentary and volcanic rocks, but the pre-existing contact-metamorphism might still remain as a factor in the process of regional metamorphism.

Mr. HARKER remarked that although new-formed felspar occurs in the most metamorphosed types of all the rocks studied, the minuteness of its grains and their pellucid appearance render it in many cases difficult to distinguish from quartz. Cyanite as a "contact-mineral" had been recorded by Lossen in the Harz.

Mr. TEALL and Dr. HATCH also spoke.

# 18. *On the* Lower Limit *of the* Cambrian Series *in* N.W. Caernarvonshire.

By Catherine A. Raisin, B.Sc. (Read February 25, 1891.)

(Communicated by Prof. T. G. Bonney, D.Sc., F.R.S.)

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In the course of some investigation of the "schists" of the Lleyn, it became necessary to compare them with the rocks in neighbouring districts. I was therefore led to make some examination of these, especially with reference to the new interpretation which has been recently proposed *. In this Mr. Blake tries to establish a great extension of the Cambrian series, increasing the length of the succession as generally accepted, and including in it the pre-Cambrian beds near Bangor and the Llyn-Padarn felsite.

## I. The Bangor District.

In the Bangor district, the pre-Arenig rocks include, as Prof. Bonney has shown, a succession of beds from the grits, which overlie the felsite, up to the strata exposed to the south and east of Bangor. This sequence Mr. Blake accepts in the main, but maintains that all these strata are to be placed in the Cambrian series, so that no pre-Cambrian rocks would be exposed here, unless, indeed, the felsite should be so classed. Briefly, the arguments brought forward in favour of this view are the similarity of strike and of lithological character.

### (a) *Lithological Character of the Strata.*

As to the latter, it is said that the beds above and below the Bryniau conglomerate are lithologically very similar, though they "ought to be decidedly different," if the conglomerate is basal Cambrian. The similarity, however, is only in the hälleflintas,

* 'On the Cambrian and Associated Rocks in N.W. Caernarvonshire,' Quart. Journn. Geol. Soc. vol. xliv. (1888) p. 271.

rocks which can hardly be considered characteristic of different periods. So far as I know, there is no clear distinction between hälleflintas of pre-Cambrian and of Cambrian age; indeed, Prof. Bonney has often insisted on the slight difference between some of the later Pebidian and the early Cambrian rocks, when they are compared lithologically. Also in the newer series at Bangor, we do not find the accumulations of coarse volcanic materials that are so marked a feature of the rocks below the conglomerate. It is true that Mr. Blake emphasizes the fact that these "are arranged in beds after the manner of subaqueous deposits," and states that they "can only be said to be volcanic, as having been derived from the denudation of volcanic products." But the question is whether these were contemporaneous volcanic products, or were denuded from those of a previous period. No evidence is brought forward for the latter view, and I imagine that the volcanic ejectamenta were rolled and partially rounded by the sea of the period to which they belong, as has been described by Prof. Bonney *.

(b) *Unconformity below the Cambrian Conglomerate.*

Even if the two sets of strata were strictly conformable, it has already been pointed out by Prof. Hughes that a local coincidence of strike would be quite compatible with a break in the succession, especially when volcanic deposits terminate the underlying series. But have we at Bangor even this local coincidence? The series, which includes the Tairffynon and Cae-Seri breccias, has been traced by Prof. Bonney with a strike about N.N.W., and Mr. Blake adds that the strike continues still N.N.W. in the grit by Nant Gwtherin, thus leading up, after some hälleflintoid rock, to the conglomerate of Bryniau. In these strata just below the conglomerate I find, however, both in the hälleflinta and also in the pebbly grit of Nant Gwtherin and Bryniau, a dip to a point S. of E., or about E.S.E., at a fairly high angle (about 50°)†; and the greenish pebbly grit well exposed south of Bryniau is a continuation of that opposite Minffordd cottages (as is allowed by Mr. Blake). Thus it occurs along a N.N.E. strike, and can be traced apparently also to the rock in the "Old Quarry," south of the road to the Mount. Hence the conglomerate to the eastward is not "strictly conformable to the underlying beds," and, to prove its position as one of a succession of Cambrian conglomerates, Mr. Blake must rely on the slender argument of lithological resemblance in hälleflintoid rocks.

* Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 483. See also Prof. Hughes on the Llyn-Padarn rocks, whose statement is quoted with approval by Mr. Blake, *op. cit.* p. 285. [Dr. Geikie, in his Address to the Geological Society in February 1891, expresses the opinion that much of the material came from contemporaneous volcanoes.]

† The dip is stated by Prof. Hughes to be about 55° S.E.; Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 682.

### (c) *Details of Outcrops.*

I have laid down on the six-inch map the outcrops of the rocks west of the great fault, but I do not find that these afford much help. As regards sundry details, Mr. Blake differs from other observers, but on what grounds I fail to see. He gives no evidence for reverting to the Survey mapping of a long tongue of felsite running up near Friddodd *, which was removed by Prof. Bonney. The only rocks that I could find in the fields near that farm are slaty rocks and felsitic grits. Moreover, the great conglomerate can be traced almost continuously from the shore to the eastern entrance of the western tunnel, instead of being, as Mr. Blake maps it, two separate masses with distinct strike. The direction of the outcrop may possibly vary, or the conglomerate may have become thicker in the neighbourhood of the straits. But we find it on the shore, we meet with indications of it by Gored Road, and probably by Hwfa Road; we see it excavated for some distance along the road east of the Look-out, and quarried at three places near new houses east of the large field to the south of the road. Again we find (possibly with a slight displacement eastwards) an indication of it just north of, and also in the road to, Friddodd; then it occurs in the quarry behind Plas Ludwig, and is well exposed by the railway at the station. Mr. Blake, it is true, is inclined to separate the two masses exposed on the east and on the west of the main fault respectively, because the pebbles on the east are "far more quartzose." But, as it seems to me, the lithological difference is not sufficiently well-marked to prove the distinctness of the two conglomerates; for, on the east of the fault, the pebbles near the Mount are mainly felsite; and, on the west of the fault, the conglomerate of the shore, although at several places almost wholly composed of felstone pebbles, also contains quartzose pebbles locally. The latter also are common in the road excavation, and in one at least of the quarries behind the new houses. But that two different conglomerates are here faulted together is very improbable. The main details in the outcrop of this conglomerate west of the fault are shown in Prof. Bonney's map; as he points out, it is not easy to interpret the structure of the district, but neither here nor to the eastward does the new view seem to be supported by any facts of importance.

## II. The Arenig Unconformity at Caernarvon and the Thickness of the Cambrian Series.

All these rocks are bounded on the east by Arenig strata, which Mr. Blake traces to Caernarvon, and to this epoch he refers the Twt-Hill conglomerate. This is mainly an arkose of the granitoid rock, from which it must therefore to a large extent have been derived. Mr. Blake's hypothesis is that the granitoid was intrusive into rocks which are now hidden; and that the Twt-Hill conglomerate originally rested upon the surface of these concealed

* Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 278.

rocks. Further, they must be supposed to date from pre-Cambrian times, since the granitoid which intrudes into them is so classed on the map; so that we should here have Arenig strata resting upon pre-Cambrian rocks. In the Survey Memoir *, Sir A. Ramsay gives the evidence for his view, that the unconformity at Caernarvon has cut out in the space of four miles the *Lingula* beds of Elidyr Fawr, which are described as being about 2000 feet in thickness. Mr. Blake's hypothesis demands much more than this—that the beds which are wanting include "all Cambrian rocks." These, according to the Survey, would be the *Lingula* beds above mentioned, the "Cambrian grits" given as 1700 feet thick †, and the "Lowest Cambrian" of the Survey Memoir. But, according to Mr. Blake's theory, below these "Lowest Cambrian" of the Survey, we have to include in the same period the old rhyolite of Llyn Padarn, the Lower Cambrian (of Mr. Blake) of Dinas Mawr, &c., and—either as equivalent to these last or below them—the Bangor beds. If we assume this to be the true succession, a very extended series of strata is wanting at Caernarvon; and also the thickness and importance of the Cambrian formation would be much increased.

## III. The Age of the Southern Felsite.

The new theory must then find its chief support in the interpretation of the southern felsite and the rocks associated with it. Here Mr. Blake agrees that the felsite was a lava older than the slates and grits to the south, but he argues that the lava flowed over the sedimentary strata now exposed to the north of it. This view is supported by two arguments—the one being the lithological character of the beds to the north of the Llyn-Padarn felsite; the other, the evidence of the quarry section at Bryn Efail.

### (a) *Lithological Comparison of the Sedimentary Strata.*

As regards the former, certain of the rocks are said to resemble strata in the Bangor district. It would be quite possible that some of the pre-Cambrian series might occur over this area, cropping out under the lower beds of the Cambrian, although I have not found any rocks which I could refer with certainty to the older formation. Mr. Blake, however, contrasts the strata north and south of the Llyn-Padarn felsite, and states that "the [two] series could not well be more distinct, considering that they are both Cambrian" ‡. But the argillites near the mineral railway along the lake, and those north of Bryn Efail and by Dinas Mawr, are certainly in many places indistinguishable from each other, while the grits of Dinas Mawr and Bryn Madog could be matched by some of those on the hillside west of the lake, or on Clegyr. It is true that the workable slates are not exposed to the north, but they may possibly be concealed beneath the extensive deposits

* 'Geol. of North Wales,' 2nd ed. p. 252.
† *Ibid.* p. 166.
‡ Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 286.

of drift, or they may be represented by beds which are less strongly cleaved *.

Mr. Blake speaks as if doubtful of the occurrence of the Dinas-Dinorwic conglomerate, noted by Dr. Hicks; but I found this rock clearly exposed at several places, with pebbles of felsite more than one inch in length (two inches and even seven inches). As boulders are scattered over the hill, it is indeed possible that the masses exposed are not *in situ*, but, for erratics, they are of very considerable size. For instance, several blocks occur along a scarp on the hillside near Pen-y-groes, two of which are quite eight feet in length. But even if this conglomerate is not *in situ*, why has Mr. Blake omitted from his section † others which undoubtedly occur, like the well-marked felsitic conglomerate east and south-east of Bryn Madog ‡, and one outcropping in a field to the east of Pont Rhythell § ?

(b) *Value of the Conglomerate as a Base.*

Mr. Blake's hypothesis does not admit the basal character of the conglomerate; it is, however, a rock very largely formed of materials from the underlying felsite, and it is difficult to understand how such an extensive denudation of the igneous rock could occur in the midst of a continuous succession. It seems rather inconsistent to assume that an important break occurs beneath the conglomerate of Caernarvon, while here no such inference is made. Moreover, in the Moel-Tryfaen exposure, Mr. Blake argues that certain of the slaty pebbles are derived from Cambrian rocks "further up the series" than the beds near Bangor. But, without a long interval, it is difficult to account for the induration and mineralogical change which have occurred in the material of the fragments. We should have to believe that, at some epoch after the deposition of one of Mr. Blake's successive conglomerates, the slates of which we now speak were deposited, indurated, modified and worn down to form some of the Moel-Tryfaen pebbles—a process of rapid manufacture indeed!

It is no doubt difficult to prove an unconformity below the conglomerate; indeed, it may even be locally absent. For instance, in the section to the east of Llyn Padarn I fail to find the clear proof of it which Prof. Green describes. The strongest evidence in his opinion was the vertical direction of the laminæ in bed A. These, however, had a suspicious aspect, and proved on microscopic examination to be igneous rock. They are thus dykes of diabase, which owe their schistosity to pressure. It is no doubt curious that so many should occur (eight at least in an area of a few square feet),

* See 'Geol. of North Wales,' 2nd ed. p. 185, note.

† Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 287.

‡ In the map (*l. c.* p. 272) Mr. Blake has marked a band of conglomerate, but has indicated it as quartzose. Of the pebbles which I noted near Bryn Madog those of felsite were in a majority, although a fair number were of quartzite. In the section (p. 287) the conglomerate is entirely omitted, as stated above, only a coarse grit (3) being shown.

§ See also reference in Survey Memoir to such outcrops; 'Geol. of North Wales,' 2nd ed. p. 185.

all narrow and of uniform width (about one inch or 1½ inch wide), and should run nearly parallel. They are not, however, quite parallel to one another, nor to the line between B and C; for they undulate slightly, and even in one or two cases seem to thin out. It is difficult to distinguish the rock into which they have intruded from a grit; but it seems to me more probably a mass of crushed felsite, which has been brought up by faults. Also the line of junction between B and C is very sharp and straight, and has rather the appearance of a fault. The failure of this evidence leaves as most probable Prof. Bonney's original interpretation, that the brecciated part below should be included with the conglomerate above.

On the hillside west of the lake, I traced the conglomerate beyond the "greenstone," and found it in close proximity to the felsite; and the conglomerate of Clegyr, according to Mr. Blake, rests unconformably on the felsite. If this is the case, and if, as I believe, we find no ground for considering the strata north of the Llyn-Padarn felsite to be earlier than it, then the Bangor series must be absent. But whether an unconformity can or cannot be indubitably proved by any section, the distinction in the physical conditions, evidenced in the rocks above and below the conglomerate, seems to justify the separation which has been made.

### (c) *Physical Conditions of the Cambrian Period.*

The base of the Cambrian in most localities appears to be clearly marked by a series of conglomerates with grits. In addition to the widespread felsitic conglomerate, which is of so recognizable a type, certain thinner layers are intercalated in many places with the succeeding grits; these may be local in their distribution, as in one example, on the hill near Dinas Mawr, where I found bands consisting almost entirely of large pebbles of diabase or a basic andesite. These deposits introduce the thick series of sedimentary strata. According to Mr. Blake, however, the Cambrian period is to include volcanic eruptions, which poured out the "mid-Cambrian" lava of Llyn Padarn. There is no evidence, as far as I know, in any other parts of North Wales, that the Cambrian period was one of volcanic activity *. The thick deposits of fine grits and slates mark a time of continuous quiet sedimentation, when the only variation was due to the shallowing of the sea; and an approach to coast-lines †. Hence, we ought to require very clear evidence from this single locality, if it is to be regarded as an exception to the general rule.

* In a recent discussion on Cader Idris, it is implied that volcanic deposits may occur; but this seems only a suggestion, and would apply to the time more immediately preceding the Arenig, not to the 'Cambrian' of the Survey; see Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 439. [Of course, if it could be proved that there is no break between the sedimentary deposits of the Cambrian and the underlying volcanics, as is suggested in the recent address of the President, which I have seen while this paper is passing through the press, this argument would not hold.]

† See Dr. H. Hicks in Quart. Journ. Geol. Soc. vol. xxxi. (1875) p. 552; Prof. T. G. Bonney, *ibid.* vol. xxxix. (1883) p. 484, and in Rep. Brit. Assoc. for 1884 (Montreal Meeting), p. 543.

Not only do we fail to find any such evidence, but we are, moreover, struck by the almost identical character of the two masses of felsite. Mr. Blake does not even suggest the existence of any difference between them; yet these two rhyolitic masses, which are practically indistinguishable from each other, are considered by him, judging by his map, to be of entirely different periods.

## IV. The Bryn-Efail Sections.

But the most important argument brought forward by Mr. Blake rests upon his interpretation of the sections at Bryn Efail (a spot just north of Llyn Padarn). They prove, in his opinion, that the fault along the northern boundary of the felsite has no existence here, and that the Llyn-Padarn lava flowed over the sedimentary rocks to the north. In short, to quote the words used, this spot "provides a crucial test"*. I examined it accordingly with the greatest possible care.

### (a) *Strata north of the Valley.*

On the north-west side of the felsite, Mr. Blake describes a low alluvial valley, and states that the rock on the opposite side "is not a conglomerate," but slates with vertical cleavage, "dipping towards the felsite at an angle of about 20°." Although no conglomerate occurs exactly in this position, we have not to go far before we reach in the fields near Bryn Madog outcrops of it associated with grits. It is thoroughly typical, with large well-rounded pebbles of felstone and of quartzite. In one field a mass of quartz-felsite intervenes, which might possibly be part of the old floor of igneous rock with its overlying conglomerate rising up again or brought up by a fault. Moreover, the argillites "quite close to the valley" cannot be said to have a very persistent dip. The general inclination for a short distance seems to be towards a point to the north of east, not therefore directly "towards the felsite"; but the beds show much small faulting and some contortions, and the dip varies in neighbouring outcrops, evidence which on the whole is rather in favour of the faulted junction marked by the Survey. Any inference drawn from a somewhat variable dip

Fig. 1.—*Section along Railway-cutting N. of Bryn Efail.*


(This section shows the argillites nearest to the valley. The dip of the strata at the southern end is somewhat variable, and is partly masked by joint-planes. Length of section about 30 yards.)

occurring along about ten yards, at the south end of the section shown in fig. 1, would not seem to have much force. But, further, it is doubtful whether the argillite exposed at Bryn Efail really represents

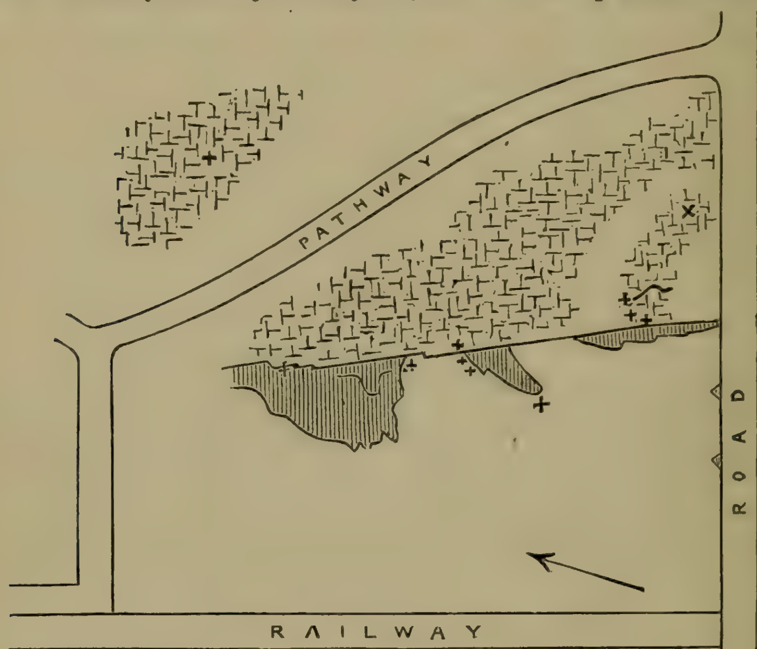
* Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 284.

the rock which is nearest to the felsite; for at Brynderw, where the valley is narrower, we find a banded gritty rock with pebbles; and the knoll of argillite itself in the field west of the main road has at its southern side (*i. e.*, nearer to the felsite) a curious purplish rock, which is fragmental and apparently of an ashy nature.

(b) *Quarry at Bryn Efail.*

We come, however, to the section upon which Mr. Blake most relies. This is afforded by a quarry, which, to quote his phrase, is "exactly on the letter E of the word Efail." That letter, as shown on the Survey map, falls on a flat alluvial plain; there is,

Fig. 2.—*Plan of Quarry at Bryn Efail.* (Scale $\frac{3}{4}$ inch = 40 feet.)




Quartz-felsite. This includes the "porphyry" (1) and some or all of the "grit" (3) of Mr. Blake.

Greenstone. This includes the greenstone (4) and most of the "slate" (2) of Mr. Blake

Dyke of fine-grained felsite.

+ Position of specimens, whence slides have been cut, showing felsite or diabase, or both.

× Slide which simulates a grit of felsite-fragments.

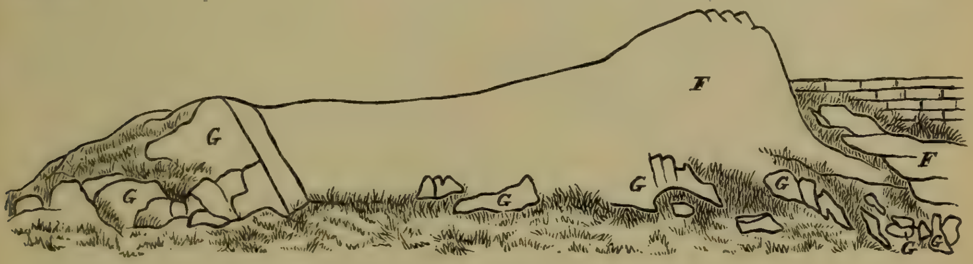
The parts left blank are covered with grass.

however, a quarry "on the west side of the road" to the north-east of the mineral railway, nearly in the angle formed by the two, which, as there is no other in the neighbourhood, I assume to be the one intended, especially as it agrees in its topographical features

with the diagram given. Mr. Blake regards the section afforded by this as a "decisive" proof of the age of the felsite. According to his description, junctions with grit and slate are here exhibited at the base of the lava-flow, and the sedimentaries show contact-alteration, which proves them to be older than the felsite. Though I carefully examined the section on more than one occasion, I failed to find any evidence in favour of Mr. Blake's view; so far as I could see, there is no slate in the quarry, and if there be any grit it is not older than the felsite. This is what I found. A greenstone dyke has been almost quarried out, and the felstone is left as a kind of miniature cliff overlooking the valley. Part of the greenstone is shown in Mr. Blake's plan; but its northward prolongation should not be represented as adjoining a band of grit, for it runs continuously in contact with the felsite; and the greenstone should not be limited on the plan to the northern end of the quarry, for it can be traced, by means of small bosses clinging to the base of the scarp of felsite, southward as far as the road, and it is seen even beyond. The high boundary-wall at this end is constructed mainly of greenstone blocks, doubtless obtained from the quarry, and two small masses still remain *in situ* built into the wall as buttresses * (figs. 2 and 3). The greenstone normally is an ordinary, rather coarse

Fig. 3.—*Quarry at Bryn Efail; face of cliff seen from lower ground.*

N.N.W. S.S.E.




F. Quartz-felsite. G. Greenstone.

dolerite, with ophitic structure, but it becomes fine-grained for the space of about a foot from the felsite, and the band $\frac{1}{8}$ inch wide along the boundary is a dirty "sahlband," or an edge still partially tachylytic. This greenstone (or diabase), in general structure and composition, agrees with those which are so common over all the North-Wales district; thus it would have been rather curious if it had belonged to a distinct and very much earlier period. The character of the edge, however, proves beyond doubt that it is intrusive in the felsite, so it may be of the same age as similar masses elsewhere. As Mr. Blake's description of his slides appeared to be very minute, I was careful to collect the most dubious-looking specimens for microscopic examination. I took most of these at intervals along the boundary of the felsite, searching for an example of the so-called

* The greenstone may have extended to the edge of the ground, which formerly sloped to the alluvial plain at the south of the quarry; if, however, a small boss of platy felsite, which occurs near the north-west of the present 'lower ground,' may be taken to mark the farther limit of the greenstone, the dyke at that part could not have been more than some twenty yards in width.

"slate." The edge shown in the slides is often quite even, but in some specimens it exhibits irregularities due to intruding tongues of greenstone or to included fragments of felsite *. At all the junctions examined the groundmass is semi-opaque, with small dull granules and incipient crystals. Specimens taken at intervals of a few inches show this structure passing into a rock containing small augites, which, however, are clear and well formed; and from this condition we trace a gradual passage into the coarser dolerite. Fibrous, actinolitic, and chloritic or micaceous aggregates have formed; and in all the examples lath-shaped felspars occur, which have been replaced by a minute crystalline mosaic; this is sometimes interrupted along a dark central line, which no doubt marks the original twinning-plane. Mr. Blake states that "chiastolite" occurs in the so-called "slate." I cannot find that mineral or anything which could possibly be mistaken for it, unless it be these altered felspars. The large felspars of the coarser dolerite show the beginning of a similar change, which is common enough in examples from many districts.

In the Bryn-Efail quarry the rock in contact with the greenstone along most of the section is undoubtedly a felsite, and not a grit as marked on Mr. Blake's plan; but at the southern end the rock does present more difficulty, even when a microscopic examination is made. The slides include rounded fragments, not unlike those in a grit, but, after careful study, I am of opinion that the rock is really the felstone, modified by crushing †. Moreover, we might fairly expect that, if a grit occurred with a southward strike, it would be traceable beyond the road; here, however, I could not find it. But even if the slides near the junction do represent a grit (and not the modified igneous rock, as I believe) this must have been formed from fragments of the felsite, and therefore (unless a pyroclastic rock, which it hardly resembles) could not be of earlier age than it. So that, in either case, Mr. Blake's argument is invalidated.

At the south end of the quarry there is a second kind of felstone, associated with that already described. This is pale grey and compact, but without porphyritic quartz or felspar. The possibility of a separation during flow, in a mass still plastic, occurred to me as an explanation. Prof. Bonney, however, suggested that probably the junction marked the intrusion of one felsite (apparently the compact rock) into another, though the two rocks might not differ much in age. This suggestion proved to be correct, for, at a subsequent visit, I traced the compact felsite as a branched dyke, penetrating the porphyritic quartz-felsite in veins of varying width.

Thus the Bryn-Efail quarry fails to provide the proof for a revolution in our ideas as to the age of the Llyn-Padarn felsite.

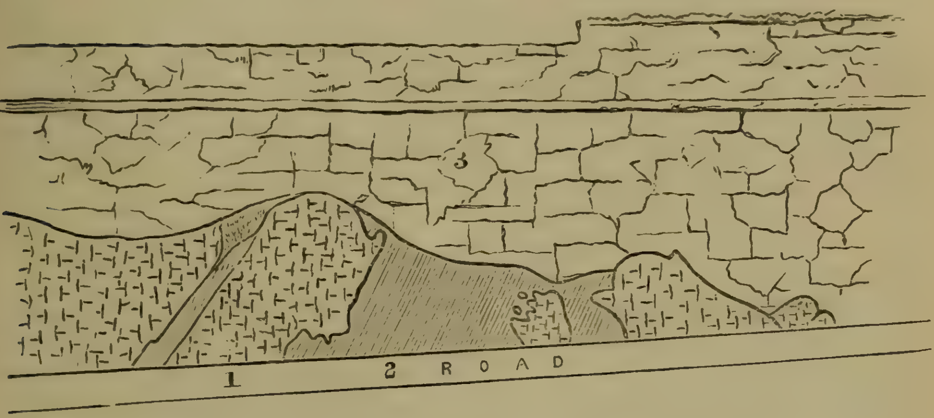
* These form, I suppose, the felsite running 'in veins into the slate' described by Mr. Blake.

† Some parts clearly exhibit pressure-structures, and suggest that other specimens, which are more difficult to distinguish from a grit, consist also of felstone subsequently crushed. Some of the apparent fragments are probably firmer parts of the felsite, which escaped modification. Such parts may be recognized in a slide cut from the heart of the mass of felstone, and were probably due to a want of homogeneity in the original lava.

### (c) *Section in the Road below the Cottages.*

The section below the cottages, under the stone wall (the "brick wall" of Mr. Blake), seems to be no more favourable to his view (fig. 4). He depicts two masses as included fragments of slate. But the western mass is a greenstone dyke, about 8 to 12 inches wide, close-grained and compact, especially at its lower part *.

Fig. 4.—*Section in Road near Bryn Efail.*




1. Quartz-felsite ............................... Porphyry of Mr. Blake.
2. Greenstone ............................... Baked slate of Mr. Blake.
3. Wall of irregular stone blocks, with a projecting ledge.

The eastern mass could not be identified in every part, owing to dirt, but a portion of it at any rate is an igneous rock of basic or intermediate character. I was able to trace with rough approximation the junction-line of two different rocks, and fortunately found two or three loose fragments, from which slides have been prepared. These prove that the other rock at the junction is felsite which has been cracked and veined with quartz and is entangled or included in the greenstone †. There seems no doubt that the latter is intrusive. Much of the rock just above the wall has been quarried

* A slide prepared from this rock exhibits porphyritic crystals of two kinds intergrown in a somewhat ophitic arrangement—felspars of earlier consolidation, which are now replaced by a micaceous aggregate, and crystals, which are ill-defined in mineral character, but may be altered felspars of later formation. The groundmass is minutely crystalline, consisting of secondary products. viridite, small flakes of chlorite, and what seems to be filmy mica, with many needles and crystals of magnetite. It contains clear granules (probably quartz) and some calcite, apparently belonging to minute amygdaloids. The rock is probably an altered andesite.

† This is apparently an andesite which has undergone subsequent alteration. The porphyritic crystals in one slide show a mosaic, partly of filmy mica, with a fringe of chlorite at the edge; in another slide they are probably present, but deformed by the crushing. In the ill-defined groundmass are developed brown or greenish chloritic films, also very numerous granules and crystals of magnetite.

away, but in the part which remains by the side of the cottages two greenstone dykes, three or four feet wide, are clearly exposed, piercing the felsite and evidently striking towards the masses by the roadside below, which I have described *.

I examined as additional illustrations specimens, obtained at other places near Llyn Padarn, of rocks which looked like slates but were only examples of slaty greenstones. It is unnecessary to describe their special characteristics, which would have no bearing on the argument under discussion. That is admittedly founded on the Bryn-Efail sections, which are said to provide a "crucial test, and thus a decisive proof." These sections, however, include no slate at all, and not any grit of earlier age than the felsite. That rock does not therefore mark a lava-flow of mid-Cambrian age; so Mr. Blake's hypothesis breaks down, and that which has been put forward by previous observers remains in possession of the field †.

## Discussion.

Prof. Blake said that small differences of strike in the beds between two parallel conglomerates were of little importance in the Bangor area; that there was no discrepancy between his text and map with regard to the tongue of felsite on the west side; and that where the Arenig conglomerate was unconformable it might come to lie upon any part of the lower series. He did not base his case as to the Llyn-Padarn mass entirely on the section at Bryn Efail. A conglomerate of felsite-pebbles to the west of the mass would certainly be important evidence, but he had failed to find any such. As to the small scattered crystals in the slaty band, he had given his reasons for judging them to have been chiastolite, though they were nothing but pseudomorphs, and he had nothing to add on this point,

* Prof. Bonney, to whom I am indebted for aid in this paper, has given me his opinion of the microscope-slides from the Bryn-Efail sections. These were fourteen in number, including seven junctions, and they were sent, as he requested, without labels, and mixed with slides from other localities. His report on them is to the following effect:—'None of them show any slate, but in ten there is diabase. The junctions all suggest, and many prove conclusively, that the latter rock is intrusive in the felsite. That the other rock which occurs in the slides is a felsite there can be no doubt, except in one case. At first, after examining this slide, I inclined, though with much hesitation, to the opinion that the rock was a grit (composed, however, entirely of fragments of felsite) which had been subsequently crushed; but after examining the hand-specimen, and using for comparison slides in my own collection from N.W. Caernarvonshire, I felt little doubt that the rock was really part of the felsite, exhibiting rather peculiar flow-brecciation and subsequent mechanical crush.'

The ten slides, which exhibit the more clearly-marked felsite, cover, as far as I can understand, the grits marked in Mr. Blake's diagram. The one just mentioned comes from a part at the south end of the quarry, and its position is shown on the plan, fig. 2, by a ×.

† See Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 137, Prof. T. McK. Hughes 'On the Pre-Cambrian Rocks of Bangor;' *ibid.* vol. xxxiv. (1878) p. 147, Dr. H. Hicks 'On some Pre-Cambrian Rocks in Caernarvonshire;' *ibid.* vol. xxxv. (1879) p. 309, Prof. T. G. Bonney 'On the Quartz-felsite and Associated Rocks at the base of the Cambrian Series in North-western Caernarvonshire.'

nor did he see any reason to doubt the correctness of his stratigraphy there.

Dr. Hicks said that he was convinced at the time Mr. Blake's paper was read that his statements in regard to the Bryn-Efail quarry were founded on erroneous observations. Since then he had obtained many important facts proving beyond doubt that Mr. Blake's attempt to overthrow the conclusions arrived at by Prof. Hughes, Prof. Bonney, and himself was based on most unreliable data; and he had intended ere long to lay these facts before the Society. As Miss Raisin had in this paper brought forward much evidence similar to that which he had obtained, he would confine his remarks mainly to that portion of the area not apparently referred to by her, viz. the neighbourhood of the Penrhyn slate-quarries. The very carefully-drawn section which he now exhibited had been prepared by Mr. J. Evans, F.G.S., late Manager of the Penrhyn slate-quarries. It shows the Cambrian succession on both sides of the pre-Cambrian ridge, and the results produced by faults. The zones on the W. side of the ridge are shown to follow one another in exactly the same order as in the more continuous section on the E. side, but the beds on the W. side have been made to dip towards the pre-Cambrian ridge by faults. The basal Cambrian conglomerate can be traced lying on an irregular pre-Cambrian floor. Dr. Hicks had visited this area on several occasions, and he was satisfied that every fossil zone known at present in the Lower-Cambrian rocks of Britain was recognizable here; he had, moreover, collected several new fossils, amongst them, in one of the higher zones, being a large *Paradoxides*. The succession clearly shows that the whole of the Lower-Cambrian beds were deposited in a gradually subsiding area, and that the materials were derived by denudation from a pre-Cambrian land containing various crystalline and volcanic rocks and indurated argillites and quartz-rocks. That these Lower-Cambrian rocks were deposited during a period in every respect to be distinguished from the so-called volcanic (Pebidian) period there could not be the least doubt; and nothing could be more unjust to those who had correctly assigned the rocks of the latter period to their proper position, below all the hitherto recognized Cambrian rocks, than to attempt to merge them in the Cambrian system.

Prof. Hughes pointed out that the Authoress had met the only strong objection to the view that the felsite ridge was pre-Cambrian—namely, the statement that the felsite altered a slate in contact with it, and therefore must be of later date. This being disposed of, we had now only to consider why the great thickness of rocks seen to pass under the Arenig on either side of the Llanberis ridge of felsite did not appear below the Arenig on the south flank of the Bangor-Caernarvon Archæan axis. He thought it was by overlap, while others were of opinion that it was by unconformity. He and they carried this great deficit to different accounts, and he saw no greater difficulty in believing that so much of the older Cambrian beds had thinned out against an Archæan shore than in admitting that the Arenig sea had here cut off the upturned edges of the older Cam-

brian rocks to that extent, an explanation of which there is elsewhere no confirmation. He referred to sections which he had described on former occasions to prove that the conglomerate of felsite-pebbles and that made up of quartz-pebbles alternated with one another, passed into one another, and behaved similarly along the whole base of what he called Cambrian.

Prof. Bonney said that at that late hour he would not enter upon the wide questions raised by the previous speakers, from whom he differed only on some points of detail, but confine himself to Mr. Blake's remarks. The discrepancy between the text and map in Mr. Blake's paper certainly existed; and the divergent strikes in the district between the Cae-Seri breccia and the Bryniau conglomerate showed that no reliance could be placed on strike either way. With respect to the main point, the Bryn-Efail pit, Mr. Blake had in vain tried to maintain his position. In that pit there was no slate, no chiastolite, no grit older than the felsite, all of which Mr. Blake had asserted to be found there. He (the speaker) had seen all Miss Raisin's microscopic sections, had examined them without labels and mixed up with other Welsh specimens, so that he might be unprejudiced, and had no hesitation in saying that as to this she was quite right, and Mr. Blake hopelessly wrong.

The President said that, wishing to preserve the impartiality of the Chair, he had refrained from taking part in the discussion, but he thought it only fair to point out that even if the particular section of Bryn Efail were abandoned by Mr. Blake, the main body of his evidence would remain in favour of his contention that in Caernarvonshire there is no proof of any pre-Cambrian rocks. He stated that his own observations had led him to the conclusion that this contention was well founded.

Mr. Peach also spoke.

## 19. *On a* Labyrinthodont Skull *from the* Kilkenny Coal-measures. By R. Lydekker, Esq., B.A., F.G.S. (Read February 25, 1891.)

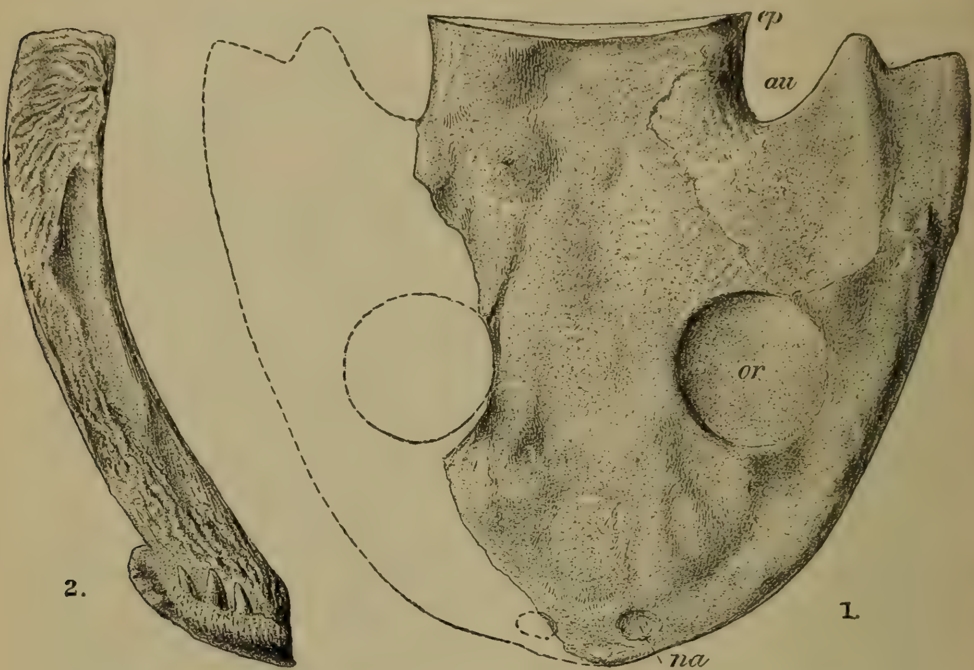
In going through the collection of Labyrinthodont remains from the Coal-measures of Jarrow Colliery, Co. Kilkenny, preserved in the Science and Art Museum, Dublin, I noticed a fragment of shale showing the lower jaw of a Labyrinthodont, which appeared to indicate a species different from any of those hitherto described from these beds. The slab in which the specimen is contained is of a slaty nature, without any of the pyritous matter which is so frequently fatal to the permanent preservation of the Jarrow fossils. On examination it appeared that by splitting the fragment the upper surface of the skull might also be revealed; and this operation fortunately proved successful. Whereas, however, the external sculptured layer of the bones of the lower jaw is exposed, in the case of the cranium the line of fission has traversed a film of shale overlying the bones, and it has only been practicable to remove this film so as to expose the sculptured surface in the left postorbital region.

As is the case with all the Jarrow fossils, the specimen has been completely flattened by pressure; but, although the width of the cranium has been doubtless thus slightly increased, the general contour is fairly well exhibited. The outline of the right side of the cranium is, indeed, in great part destroyed, owing to the reflection of its maxillary border on to the inferior surface of the slab. On the left side of the cranium the contour is, however, entire. The extremity of the premaxillæ, carrying three large conical teeth on the left side, is bent over on to the inferior surface of the slab, and thus overlaps part of the mandibular symphysis. The innermost tooth is separated by an interval of about 0·4 inch from the middle line; and all the teeth pass on the outer side of the mandible. The left mandibular ramus is fairly well preserved, but the opposite one has been much crushed and distorted, and is confused with some of the bones of the right side of the cranium.

Fig. 1 (see next page) gives the outline of the cranium, the contour of the right side restored from the opposite one. From this figure it will be seen that the skull has a parabolic contour, with a length of nearly four inches and a width of nearly as much. The orbits are large, nearly circular, separated by an interorbital bar wider than their transverse diameter, and situated mainly in the anterior half of the skull. The supra-occipital border forms an expanded and slightly concave line, terminating in small epiotic cornua, which are directed slightly outwardly, and externally to which is a small slit. The larger auditory slits are very deep and narrow. The contour of the left mandibular ramus given in fig. 2 shows a high degree of arcuation, corresponding with the shape of the cranium.

Compared with the smaller imperfect cranium figured by Prof.

Huxley in the Trans. Roy. Irish Acad. vol. xxiv. pl. xxiii. fig. 2, under the name of *Erpetocephalus rugosus*, it will be evident that the two are generically identical. The last-named skull has, however, a length of only 2·5 inches, and since a number of specimens have nearly the same dimensions and never exceed them*, it is




*Skull of Ichthyerpetum hibernicum.* $\frac{2}{3}$ natural size.

1. Outline of the cranium: *ep*, epiotic cornu; *au*, auditory slit; *or*, orbit; *na*, nares.
2. Left mandibular ramus. The extremity of the premaxilla is seen to be bent down upon the symphysis.

probable that its superior size would alone serve to indicate the specific distinctness of the present specimen.

If, however, the two figures be compared, it will be seen that the auditory slits are deeper, the epiotic cornua less produced outwardly, and the interorbital bar relatively less wide. In the specimen before us, I therefore think it most probable, although I cannot be absolutely certain, that we have an example of a distinct species, which I propose to provisionally name *Ichthyerpetum hibernicum*; the generic identity of *Erpetocephalus* with *Ichthyerpetum* having been shown by myself † on a previous occasion.

The interest of the specimen does not, however, lie in the question as to whether or no it indicates a new species, but as regards the relationships of the genus to which it belongs. In the work just

* In the British-Museum Catalogue, from the belief that the specimens were imperfect, the length is given as about 3·1 inches.

† Cat. Foss. Rept. & Amphib. Brit. Mus. pt. iv. pp. 168, 169.

cited, from the production outwardly of the epiotic cornua, and in the belief, as suggested by Huxley, that the damaged skull figured by him was imperfect anteriorly, I placed *Ichthyerpetum* next to *Nyrania*. The forward position of the orbits and the much more nearly parabolic contour of the present almost perfect specimen show, however, that this relationship is not nearly so close as I had thought. If, however, the figure of the skull of *I. hibernicum* be compared with that of *Bothriceps australis*, Huxley*, from the Hawkesbury beds of New South Wales, the resemblance is so striking as to leave little or no doubt that we have to do with closely allied forms. It is true, indeed, that the present skull differs by the deeper auditory slits and relatively wider interorbital bar. These, however, are comparatively slight points of difference, and we note almost as much difference from *Bothriceps australis* as regards cranial contour in the skull of *Micropholis Stowi*, Huxley †, from the Karoo system of the Cape. The pustular nature of the cranial sculpture of *Micropholis* (*Petrophryne*) indicates, on the other hand, its generic distinctness from *Ichthyerpetum*.

I take it, therefore, that *Ichthyerpetum* is a member of that group ("Brachyopina" of Miall) containing *Brachyops*, *Bothriceps*, and *Micropholis*; all of which are characterized by their more or less parabolic skulls and forwardly-placed orbits. The circumstance that *Ichthyerpetum* has discoidal vertebral centra is very important as helping to determine the affinities of the group. This fact further tends to lend support to the view (provisionally adopted in the British-Museum Catalogue) that the so-called "Brachyopina" are closely allied to *Dendrerpetum* of the Lower Permian and Carboniferous, which is likewise stated to have discoidal vertebræ, but in which the orbits are placed more posteriorly than in the genera above-named. Since, however, there is a great amount of variation in this respect in the different genera, it does not appear that on this ground alone the so-called "Brachyopina" should be separated from the *Dendrerpetidæ*.

One other important matter in connexion with the skull before us remains for consideration. In 1862 Prof. Huxley ‡ described and figured the skeleton of a Labyrinthodont from the Lower Carboniferous of Gilmerton, near Edinburgh, under the name of *Pholidogaster pisciformis*. Unfortunately only the ventral aspect of this specimen is exposed, so that we have no knowledge of the frontal aspect of the skull, in consequence of which it has been impossible to determine the affinities of the genus. On comparing the inferior surface of the Jarrow skull with *Pholidogaster*, a most striking resemblance is seen to exist between the mandibles of the two specimens. The resemblance is, indeed, sufficiently close to render it nearly safe to affirm that *Pholidogaster* had a parabolic skull of slightly larger size than the specimen under consideration; although it might, perhaps, be unsafe, on this evidence alone, to say positively

* Quart. Journ. Geol. Soc. vol. xv. (1859) pl. xxii. fig. 1.
† *Ibid.* pl. xxi.
‡ *Ibid.* vol. xviii. p. 294, pl. xi. fig. 3.

that the two forms are generically identical. In describing the vertebral skeleton of *Ichthyerpetum*, Prof. Huxley remarks that, in comparison with the other Jarrow forms, "it is more pisciform"; and in noticing the impressions that appear to have been formed by the ventral scutes, he observes that "the ventral surface of the trunk presents numerous minute, more or less parallel ridges, pointed at each end, and taking a general course obliquely downwards and forwards to the middle line." In describing *Pholidogaster pisciformis*, the Professor first of all states that he proposes the name on account of its "fish-like form"; and in treating of the ventral scutes or scales, observes that "they are seen to be somewhat oat-shaped," and are "so arranged as to form oblique series, directed inwards and forwards, and meeting in the middle line." When we recollect that the term "inwards" is precisely equivalent to "downwards" in these cases, it will be apparent that the description of *Ichthyerpetum* might be transferred to *Pholidogaster*, or *vice versâ*; and I am thus strongly inclined to believe that the latter is founded upon a larger species of the former. Additional evidence in favour of this opinion is afforded by Prof. Huxley's description of the skull of *Pholidogaster*. Here he observes that "in front of the symphysis of the mandible, the under surface of the premaxilla is visible, bearing the stumps of two teeth. These teeth are situated at some distance (about 0·7 of an inch) from the middle line, and pass outside the ramus of the mandible. They are conical, and round in transverse section. . . . . The bases of the teeth are marked by strong longitudinal grooves." Remembering that we have three in place of two premaxillary teeth remaining in the skull of *Ichthyerpetum hibernicum*, this description will apply word for word.

Further evidence is, however, afforded by the skull of *Dendrerpetum*, where, according to Dr. Fritsch's figure *, the premaxillary teeth are enlarged, separated by a diastema in the middle line, deeply fluted at their base, and, judging from the outward inclination, apparently biting outside the mandible.

In this connexion I find that Sir J. W. Dawson † long ago pointed out that *Pholidogaster* was closely allied to *Dendrerpetum*; and it is to my own mind not at all improbable that they may prove to be identical.

All these lines of evidence point, therefore, very clearly to the conclusion that *Ichthyerpetum* and *Pholidogaster* are identical, and also suggest that they may be inseparable from *Dendrerpetum*, which is the earliest of the three names. I refrain only with hesitation from adopting the name *Pholidogaster* in place of the later *Ichthyerpetum*; but in view of the possibility that both these may prove to be synonyms of *Dendrerpetum*, I have taken the course of referring the specimen to the genus to which I absolutely know that it belongs.

I may avail myself of the opportunity of observing that any objec-

* 'Fauna der Gaskohle,' vol. ii. pl. xlix. fig. 1.

† 'Air-Breathers of the Coal Period' (1863), pp. 22, 23.

tion that might be taken against the identification of *Ichthyerpetum* and *Pholidogaster* on the ground that, while the type species of the former occurs in the Upper, that of the latter was obtained from the Lower Carboniferous, is nullified by the circumstance that both *Loxomma* and *Anthracosaurus* (and apparently the same species of each genus) range through the whole of the Carboniferous system.

Further, if these two Labyrinthodonts be really generically identical, it will be obvious that the vague suggestion of the rhachitomous nature of the vertebral column of *Pholidogaster*, made in the British-Museum Catalogue, at once falls to the ground.

Finally, taking it as proved that *Pholidogaster* and *Ichthyerpetum* are closely allied to the so-called "Brachyopina," we now have evidence that a type of Labyrinthodonts common throughout the European Carboniferous (and unknown there after the base of the Permian) was represented in the Lower Gondwanas (? Upper Permian of India) by the genus *Brachyops*, while, as we go farther eastwards, we find it surviving in the Hawkesbury beds of Australia (which are of somewhat later age), where it is represented by *Bothriceps*; a member of the latter genus, together with the allied *Micropholis*, also occurring in the great Karoo system of South Africa, some portion of which is probably the equivalent of the Hawkesbury beds. This seems, therefore, to be another instance of the persistence of types in the Indian, Australian, and Ethiopian regions during long ages after their total disappearance from the Palæarctic area.

## 20. *The* Tudor Specimen *of* Eozoon. By J. W. Gregory, Esq., F.G.S., F.Z.S., of the British Museum (Nat. Hist.). (Read March 11, 1891.)

The unanimity with which the view of the organic origin of *Eozoon canadense* was received on its announcement in 1865 by Sir William Logan, Dr. (afterwards Sir J. W.) Dawson, and Dr. W. B. Carpenter *, in the Quarterly Journal of this Society, was first seriously broken by the publication, in the succeeding volume, of the memoir by Professors King and Rowney "On the so-called Eozoonal Rock" †. In the following year the Quarterly Journal contained a series of "Notes on Fossils recently obtained from the Laurentian Rocks of Canada, and on objections to the organic nature of *Eozoon*," by Dr. (afterwards Sir J. W.) Dawson ‡, the most valuable contribution in which was the description of a specimen found by Mr. H. G. Vennor in a limestone belonging to the Hastings series at Tudor, Hastings county, Ontario. This was identified as *Eozoon canadense*, though as possibly a new variety, by Sir J. W. Dawson, who seemed to consider that this discovery relieved him of the necessity of making any detailed reply to the arguments of his critics, as "furnishing a conclusive answer to all those objections to the organic nature of *Eozoon* which have been founded on comparisons of its structures with the forms of fibrous, dendritic, or concretionary minerals—objections which, however plausible in the case of highly crystalline rocks, in which organic remains may be simulated by merely mineral appearances readily confounded with them, are wholly inapplicable to the present specimen" §.

The importance of the new discovery depended on the fact that all the previously known specimens of *Eozoon* consisted of aggregations of calcareous with serpentinous minerals, a fact upon which great stress had been laid by the objectors to its organic origin. But it was claimed by Sir J. W. Dawson that the Tudor specimen was a true *Eozoon* preserved in limestone alone. The claim was not altogether a new one, as Sir J. W. Dawson had previously discovered *Eozoon* in the Madoc limestone, and had emphasized the value of this point in a letter which was published by Dr. Carpenter among his 'Supplemental Notes' ‖. But, as was admitted ¶ in the memoir on the Tudor specimen, Sir J. W. Dawson "did not then venture to describe as a fossil" this very imperfect fragment,

* W. E. Logan, 'On the Occurrence of Organic Remains in the Laurentian Rocks of Canada,' Quart. Journ. Geol. Soc. vol. xxi. (1865) pp. 45–50; J. W. Dawson, 'On the Structure of certain Organic Remains in the Laurentian Limestones of Canada,' *op. cit.* pp. 51–59, pls. vi. & vii.; W. B. Carpenter, 'Additional Note on the Structure and Affinities of *Eozoön canadense*,' *op. cit.* pp. 59–66, pls. viii. & ix.

† Quart. Journ. Geol. Soc. vol. xxii. (1866) pp. 185–218, pls. xiv. & xv.

‡ *Ibid.* vol. xxiii. (1867) pp. 257–265, pls. xi. & xii.

§ *Ibid.* pp. 257–258.

‖ 'Supplemental Notes on the Structure and Affinities of *Eozoon canadense*,' Quart. Journ. Geol. Soc. vol. xxii. (1866) p. 228.

¶ *Ibid.* vol. xxiii. (1867) p. 261.

and but for the discovery of better material probably no value would have been attached to it by other writers. But as the disbelievers in *Eozoon* were as ready then as now to admit that the production of such a specimen would at once settle the whole controversy and conclusively establish its organic origin, the claims based by Sir J. W. Dawson on the Tudor specimen had an enormous influence in confirming geologists in their acceptance of the supposed Laurentian fossil. The value attached to the preservation of *Eozoon* in a limestone may be illustrated by the following quotation from Sir Warington Smyth's Presidential Address to the Geological Society in the year of the publication of the Tudor memoir:—"The elaborate arguments of Messrs. King and Rowney in favour of the mineral origin of 'Eozoonal' structure had at one time a strong show of support in the fact that these appearances were always observed in serpentinous limestones (ophicalcites) only. . . . . But the announcement made by Dr. Carpenter, in the Quart. Journ. Geol. Soc. for August last, of Dr. Dawson's discovery of *Eozoon* preserved in carbonate of lime pure and simple would appear to close the discussion"*.

Sir J. W. Dawson's view apparently is that the specimen consists of a slab of *Eozoon* 6 inches long by 4½ inches wide and 2 lines in thickness, broken off at right angles to the septa. Profs. King and Rowney † subsequently pointed out the improbability of so large and thin a slab being thus formed transverse to the laminæ, and suggested that the calcite veins were merely produced by infiltration into a series of fissures or cracks.

But as this opinion was only based on second-hand information no great weight seems ever to have been attached to it, and from that time onwards the Tudor specimen has always remained the great obstacle to the acceptance of the mineralogical explanation of the structure of *Eozoon*. Thus Prof. Moebius, after an examination of the specimen, told Mr. C. D. Sherborn and myself that it alone had ever suggested to him doubts as to the truth of his conclusions. Prof. Nicholson, moreover, allows me to say that he has always felt that if the Tudor specimen should exhibit the characteristic canal-system of *Eozoon*, it would afford a strong presumption in favour of the view that *Eozoon* is organic; and that after an examination of the specimen he saw nothing that would justify the assertion that its nature was organic, or even that the specimen was one of *Eozoon* at all.

The specimen having recently been sent to England for examination by a committee which had arranged to work through the enormous mass of Eozoonal material collected by the late Dr. W. B. Carpenter, I have had the opportunity for a careful study of it. For this I am indebted to Dr. P. H. Carpenter, F.R.S.; I must also express my best thanks to Dr. R. A. C. Selwyn, C.M.G., for his kindness in allowing a further section to be prepared, which has been skilfully cut by Mr. Ryley. Dr. Selwyn has moreover allowed

* *Op. cit.* Proc. p lxiv.

† 'On *Eozoon canadense*,' Proc. Roy. Irish Acad. vol. x. (1870) p. 511.

the specimen to remain for some time in England, and thus several specialists, including Profs. Moebius and Nicholson, have been enabled to examine it.

Considering, therefore, the importance that has been attached to this specimen throughout the whole controversy, it has been thought that a redescription may be of value. The note upon it is sent to this Society, as the plates illustrating the specimen were first published in its Journal.

(a) *General Form.*—As reference to the original figure* will show, the specimen consists of a series of narrow white bands of calcite separated, though often imperfectly, by bands of a darker-coloured limestone, which are often continuous with the matrix on either side. The former, which are neither as numerous or regular in the specimen as in the figure given in the Journal, are wider at one end than the other, and thus mark off a somewhat clavate-shaped area of the slab. The view taken by Sir J. W. Dawson is that the white bands of calcite form the original "intermediate skeleton" of an *Eozoon* colony, while the darker layers between them represent the "body-cavities" filled up by the material that forms the mass of the limestone.

(b) *The Microscopic Structure of the Rock.*—The rock itself is a calc-mica-schist in which the remains of the bedding-planes are recognizable though obscure†. When examined under the microscope the cleavage is seen to be due to the development of crystals of a white mica, while the dark colour arises from minute particles of graphite scattered irregularly throughout. A few small quartz-fragments, which may represent original sand-grains and patches of a grey calcareous mineral (probably dolomite), are also to be noted. Mr. Teall has very kindly examined the slide; he observes that it reminds him much of some of the Assynt limestone which has been altered by contact with granite, and, as he accepts the micas as authigenous, there can be no doubt that the rock is a true schist. The abundance of graphite gives it a resemblance to the grey "cipolinos" of the St. Gothard, but it is less altered than these.

(c) *The "Eozoonal Bands."*—The "*Eozoon*" is preserved on the surface of a slab of the calc-mica-schist, and an examination with the naked eye shows that three sets of structure traverse the rock. The cleavage is parallel to the face of the slab, and this it was that Sir J. W. Dawson regarded as "the plane of stratification," a view which an examination of a transverse section clearly shows to be untenable. The true bedding-planes cross those of cleavage at a fairly high angle and run parallel to the obliquely-truncated upper margin; their traces on the sides are intensely crumpled and contorted. They can be clearly seen on the upper surface, but are not shown in the original figure. They are, however, well marked in a

* Quart. Journ. Geol. Soc. vol. xxiii. (1867) pl. xi.; reprinted in Amer. Journ. Sci. ser. 2, vol. xlvi. (1868) pl. i.; Dawson, 'The Dawn of Life' (1875). pp. 111, &c.

† The rock is a limestone, as Sir J. W. Dawson has stated; but on close examination it is seen to belong to the schistose-micaceous variety termed by petrologists a calc-mica-schist.

photograph, a copy of which has kindly been presented by Mr. H. B. Woodward to the British Museum (Nat. Hist.). The third set of structures are the white calcite-bands for which an organic origin is claimed. These consist of veins of crystalline calcite, which rarely extend to a depth of more than $\frac{1}{10}$ inch. Their relations to the rest of the rock are very irregular. They may end off abruptly or break up into slender ramifications, which are sometimes connected by other calcite-bands developed along the cleavages, so that a reticulate series results (see fig. 4, facing p. 354). The boundaries between the "Eozoonal" layers and the normal calc-mica-schist are excessively irregular, as is seen in fig. 3; there is no "proper wall" to be seen at the junction—at least, I have been unable to recognize even such traces as might have been expected had the pores been obliterated by the infiltration of calcite, as has been suggested *. Nor does the evidence for the canals seem more satisfactory. Sir J. W. Dawson figured † as such a series of carbonaceous inclusions, and though by the kindness of Dr. Selwyn I have been enabled to study the original slide, I fail to see any reason for regarding them as the infillings of organic canals. There seems no essential difference between the graphitic bodies in the matrix and those in the calcite, though the latter are as a rule more minute in size. In their irregularity of form and arrangement they seem to be very different from the canals in any known foraminifer. Sir J. W. Dawson's own figure, magnified though it is 120 diameters, fails to carry conviction of the origin which he assigns to them.

After a careful examination of all the slides and figures, and consideration of Sir J. W. Dawson's interpretation, I must confess myself absolutely unable to recognize in the specimen any trace of the "proper wall," "canals," or "stolon passages" which are claimed to occur in *Eozoon* ‡, or any reasons for regarding the calcite bands as the "intermediate skeleton" of a foraminifer. There are points in Sir J. W. Dawson's figure which might pass as "stolon passages," but these appear very different in the photograph, and the specimen agrees with the latter.

But the case against the organic origin of the Tudor specimen does not rest on negative evidence alone: in addition there seems plenty of positive proof against this view. The circumstance that while the rock has been intensely cleaved and crumpled the twin laminæ and the planes of crystalline cleavage in the calcite-bands are not bent, suggests that the bands are of secondary origin; and this seems to be conclusively established by the fact that the bedding-planes can be often traced right across the specimen, traversing the limestone in the supposed body-cavities, and broken only by the calcite-layers (see fig. 1). This is faintly indicated in the photograph

* Quart. Journ. Geol. Soc. vol. xxiii. (1867) p. 259.

† *Ibid.* pl. xii. fig. 1.

‡ But it should be noted that Dr. Carpenter abandoned the view of the organic origin of the 'proper wall': see Whitney & Wadsworth, 'The Azoic System and its proposed subdivisions,' Bull. Mus. Comp. Zool. (Harvard) vol. vii. (1884) pp. 535–536, and J. W. Gregory, 'Science Gossip,' vol. xxiii. (1887) p. 103.

already referred to, though as the bedding-planes do not come out clearly till the surface be wetted, they are not well shown. The explanation of the relations of the bedding-planes to the calcite-bands on the organic hypothesis is beset by three difficulties: 1st, it requires that this thin strip of *Eozoon* should have been buried vertically, which, considering its proportions, is not very probable; 2nd, had it been covered by the deposition of a calcareous mud we might have expected this to have been piled up around it, so that the stratification should not meet it with such regularity; and 3rd, had the body-chambers been filled by the washing in of the limestone material, any planes of bedding would have accommodated themselves to the irregularities of the cavities, and the bedding would hardly have been continued so exactly in the same straight line across all the layers traversed by any plane. It seems to the writer quite impossible to account for the continuity of the bedding-planes across the specimen, except on the view that the calcite-bands have been formed later than the dark layers of amorphous carbonate of lime between them.

The fact that the cleavage-planes are not continued across the calcite and that no mica has been developed in this would alone be sufficient in the minds of many geologists to settle the relative ages of the crystalline and amorphous parts of the limestone. But it cannot be expected that those who regard the foliation of the pre-Cambrian schists as an original structure in the rocks will attach much weight to this argument.

(d) *The Origin of the Calcite-bands.*—It now remains to be considered what explanation of the origin of the crystalline calcite can be offered without the assistance of any organic agency. Profs. King and Rowney suggested that they were formed by the infiltration of calcite into a series of cracks, but this is not an adequate explanation. In some cases a small patch of the calc-mica-schist can be seen completely surrounded by the calcite, and this alone is sufficient to overthrow the fissure hypothesis; moreover, the remarkable irregularity of the junction of the crystalline and amorphous carbonate of lime, the distribution of the graphite particles in the former, and the absence in it of any banding, are all difficult of explanation on this view.

It seems more probable that the calcite-bands were formed by the solution of the limestone and its redeposition along the lines on which the water percolated through the rock. To explain why these curved bands were formed is probably impossible without a knowledge of the position which the slab occupied when *in situ*. The whole surface of the specimen has been slightly altered to a depth of half an inch. The irregularity and apparent capriciousness of the action by which the bands were formed are too well known for any serious objection to be raised to this explanation while the field relations of the specimen are unknown. In most cases the solvent has acted along the lines of weakness and started from the weathered surface. As a rule, the secondary calcite has been developed along the bedding-planes, but at times some has also been

formed along the lines of cleavage. In one case a thin vein extends across the whole thickness of the slab along a line that was possibly a true crack. In one or two places the solvent acted along a kind of minute pipe, so that the calcite appears as a circular patch entirely surrounded by the calc-mica-schist. Some of the bands have the whole thickness formed of one crystal, but in other cases they are occupied by a mosaic, the separate constituents of which have the characteristic irregular polygonal outlines.

There is a further convincing proof of the later origin of the crystalline calcite where projections of the calc-mica-schist extend into the calcite; this has been deposited in such intimate connexion with these patches that a certain amount of crystalline continuity has been established, and the cleavage-planes pass uninterruptedly from the one to the other (fig. 3). Further, the regular distribution of the graphite seems to show that the transparent calcite was formed by the solution and recrystallization of the schist, as the inclusions appear to have been primary impurities rather than to have originated as infiltrations.

In conclusion, it should be pointed out that no opinion is here expressed as to the nature and origin of the other types of *Eozoon.* It is only maintained that as the Tudor specimen lacks all the structures (except the mere alternation of irregular layers of different composition) which caused the typical *Eozoon* to be regarded as organic, the argument based upon it to the effect that all these structures have been preserved in calcite alone is not sustained by a further examination of the specimen. But if it still be contended that Sir J. W. Dawson has rightly identified this Tudor specimen, then *Eozoon* is not organic, as in this case it is due to secondary alterations produced long after the consolidation of the limestone, and even after the metamorphic action which converted it into a calc-mica-schist.

(e) *Stratigraphical Position of the "Hastings series."*—In regard to the stratigraphical position of the specimen it should be remarked that the Hastings series, including the Tudor limestone, cannot now be regarded as Lower Laurentian, to which horizon it was assigned by Sir Wm. Logan in 1867 *. The detailed mapping of Mr. H. G. Vennor † has conclusively disproved this opinion and established the correlation of these beds with the Grenville series, and thus led to the abandonment of the term "Hastings series" as applied to a separate group ‡. It is quite possible, as Dr. Lawson § has

* 'On new Specimens of *Eozoon*,' Quart. Journ. Geol. Soc. vol. xxiii. (1867) p. 254.

† 'Report of Mr. H. G. Vennor on Hastings County,' Rep. Progress Geol. Surv. Canada, 1866–69 (Montreal, 1870), pp. 143–171; H. G. Vennor, 'Reports of Surveys in the counties of Renfrew, Pontiac, and Ottawa, &c.,' *op. cit.* 1876–77 (1878), pp. 244–320.

‡ *Op. cit.* 1876–77, p. 256.

§ A. C. Lawson, 'The Archæan Geology of the Region North-west of Lake Superior,' p. 86 of the 'Études sur les Schistes cristallins,' of which separate copies were issued at the London Session of the Congrès géologique international, but have not yet been published.

suggested, that the limestones may be inclusions in the intrusive gneisses. But, at any rate, the rock itself is post-Laurentian and is now included by Messrs. Selwyn* and Vennor in the Huronian, while the bands of crystalline calcite to which it owes its fame may have been formed at any time between the cleavage of the rock and the discovery of the specimen by the officers of the Canadian Geological Survey.

## EXPLANATION OF FIGURES.

Fig. 1. The lower part of the Tudor specimen ; nat. size. The part in the upper portion of the left-hand side of the specimen shows the unweathered surface of the slab with the lines of structure (regarded as bedding-planes). To the right of this is the weathered surface containing the white 'Eozoonal' bands (*b*); the latter are seen to interrupt the bedding-planes (as at the lower *b*), to be developed along them (as at *d*), or to terminate abruptly against them (as at *e*). This can best be seen when the specimen is moistened.

Fig. 2. Section transverse to the 'Eozoonal' bands along the right-hand margin of fig. 1 ; $\times 2$ diam. In the lower part the schistosity is recognizable, but in the layer containing the 'Eozoonal' bands it has been obliterated ; the general form of the 'Eozoonal' bands in cross-section is shown (but see fig. 3); one of the bands is continued across the specimen along a crack.

Fig. 3. One of the 'Eozoonal' bands of the same slide as fig. 2 ($\times 30$ diam., reduced $\frac{2}{3}$), showing their relations to the weathered calc-mica-schist: *b* is one of the 'Eozoonal' bands, and *b′ b′* are parts of the two next bands; they show the irregularity of the junction of the crystalline calcite with the rock, parts of the latter projecting into the former; in places the cleavage of the calcite is continued across the inclusions of the rock (as at *a*). In addition to the particles of graphite (*g*), the matrix contains crystals of mica (*m*), but the foliation has been obliterated.

Fig. 4. Another part of the same slide, showing above the weathered surface with the 'Eozoonal' bands, and below the normal calc-mica-schist. One of the 'Eozoonal' bands (*b*) is continued down across the slide ($b^1$), and in places (as $b^2$) branches along the planes of schistosity.

## Discussion.

Mr. Sherborn remarked that the Society must be congratulated on having at last the Tudor specimen upon the table. It was fortunate, too, that the specimen had been examined by Mr. Gregory. He agreed with Professor Moebius that the Tudor specimen had nothing whatever to do with the Eozoonal structure, beyond the fact that both had somewhat parallel layers of calcite. He had no hesitation in saying that, had Dr. W. B. Carpenter seen the Tudor specimen at the time of the publication of the first account of it, he could not have put his name to the statements.

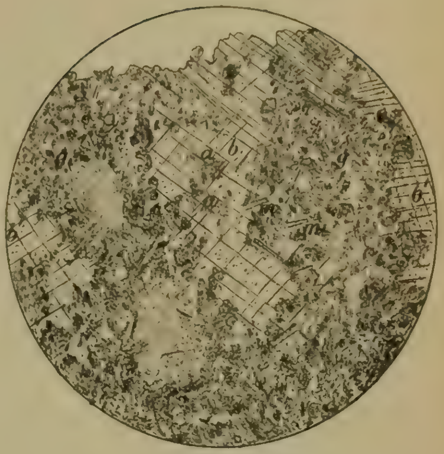
The President regretted that no palæontologist was present to break a lance in support of the organic origin of *Eozoon*. He had

* R. A. C. Selwyn, 'Report of Observations on the Stratigraphy of the Quebec Group,' Rep. Progress Geol. Surv. Canada, 1877–78 (Montreal, 1879), p. 14 A.

Fig. 1.

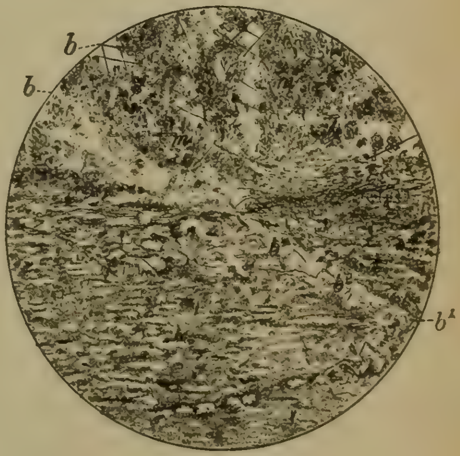

Natural size.

Fig. 3.



× 30 diam. (red. $\frac{2}{3}$).

Fig. 4.



× 30 diam. (red. $\frac{2}{3}$).

Fig. 2.

× 2 diam.

THE TUDOR SPECIMEN OF "EOZOON."

examined the Tudor specimen, and could not recognize in it the Eozoonal structure with which he was familiar in the ordinary specimens. At the same time the specimen, though by no means so distinct as the published plate of it represented, had a curiously organic-looking aspect; and he thought it probable that the palæontologists would not surrender it to the mineralogists without a more vigorous struggle than had been attempted that evening.

Prof. BLAKE, having satisfied himself of the inorganic nature of *Eozoon* at St. Pierre, had been to Tudor without obtaining any light on the specimen. The crystallization of the material and its passing into the cracks might be due to subsequent mineralization, and the evidence of bedding passing across the specimen was doubtful, but the specimen itself was perfectly convincing. He was sure that Sir J. W. Dawson never expected the so-called "fossil" would die out like cracks within $\frac{1}{8}$ inch of the flat surface, which was quite incompatible with its being organic.

The AUTHOR, in reply to Prof. Blake, recapitulated the evidence in favour of the bedding-planes, and stated that several objections to Sir J. W. Dawson's explanation of the thinness of the specimen were stated in the paper. The supposed definite margin of the specimen was due to the fact that the calcite-bands had only been developed on the weathered surface of the slab. Every English palæontologist who had examined the specimen and slides agreed that it was inorganic.

## 21. *On a* Phosphatic Chalk *with* Belemnitella quadrata *at* Taplow. By A. Strahan, Esq., M.A., F.G.S. (Read March 25, 1891.)

[Communicated by permission of the Director-General of the Geological Survey.]

While engaged in the course of my duties in arranging the specimens collected for the Rock Collection in the Museum of Practical Geology, my attention was attracted by a chalk of unusual character. The specimen was collected by John Rhodes, when the second edition of the "Geology of London" (Memoirs of the Geological Survey) was in preparation, from an old pit at the Lodge of Taplow Court, the seat of W. H. Grenfell, Esq. By permission of the Director-General, I examined the pit, and made the following descending section :—

*Lodge Pit, Taplow Court.*

| | ft. | in. |
|---|---|---|
| Soft white chalk, top not seen | 12 | 0 |
| passing down into | | |
| Brown chalk with *Ostrea acutirostris*, Nilss., *Belemnitella quadrata*, Defrance (both abundant), *Echinocorys vulgaris*, Breyn., and *Cidaris sceptrifera*, Defrance, about | 8 | 0 |
| White chalk traversed by numerous tubes and cavities filled with brown chalk; a hard and blocky top, forming a marked floor to the brown chalk above | 3 | 0 |
| White chalk, mostly inaccessible, and not examined in detail | 14 | 0 |
| White chalk with scattered brown grains | 2 | 6 |
| passing down into | | |
| Brown chalk, about | 4 | 0 |
| Hard crystalline chalk with nodular structure and greenish markings (like Chalk Rock), about | 1 | 0 |
| White chalk, piped with brown chalk as above | 1 | 10 |
| A sandy brown layer | 0 | 0½ |
| White chalk, piped with brown chalk | 2 | 6 |
| White chalk to the bottom of the pit, the first flints occurring 12 feet below the lower band of brown chalk | 15 | 0+ |

At the top of the pit there occurs a thin streak of intermingled red clay and green sand, with a few green-coated flints, which has clearly been washed but a few feet down from the Tertiary outlier on which Taplow is situated. The true base of the Tertiary strata lies probably not more than 10 feet above the highest chalk seen in the pit. The dip in the pit and along the hillside northwards is about E. 10° S. at 4° or 5°. In the memoir referred to (vol. i. p. 77) a correlation of this chalk with the well-known Margate Chalk, or the zone of *Marsupites*, is suggested on the evidence of the occurrence of *Belemnitella quadrata* and the scarcity of flints. The total thickness of Upper Chalk existing in the neighbourhood is believed to be between 250 and 300 feet.

[A shaft, which has been sunk in the hillside above the pit since the reading of this paper, gives the exact depth of the phosphatic

bands below the base of the Tertiary strata. The following measurements were made by Mr. Lodge, and kindly supplied to me by Mr. Grenfell.—May, 1891.]

| | | ft. | in. |
|---|---|---|---|
| Reading Beds. | Clay | 7 | 0 |
| | Green sand with green-coated flints | 2 | 6 |
| Upper Chalk. | White chalk | 18 | 0 |
| | Brownish white chalk | 2 | 0 |
| | Brown chalk [upper phosphatic band] | 11 | 0 |
| | Hard white chalk | 12 | 0 |
| | Soft brown chalk [lower phosphatic band] | 4 | 0 |
| | Very hard white chalk | | |
| | | 56 | 6 |

The specimens from which the following notes have been drawn up were collected from the brown bands of the above section. Both bands owe their colour to a multitude of brown grains, and pass up gradually into a rock less rich in brown grains, and of a pale brown or greyish tinge. The chalk is irregularly bedded, perhaps current-bedded, and traversed by irregular joints, so as to break readily up into blocks, which crumble into a rounded form and finally into powder. Its friability forms a marked feature, and is due to the softness of a white chalky paste in which the brown grains are embedded. Under the microscope these grains are seen to be almost entirely of organic origin, foraminifera, the prisms of *Inoceramus*-shells, and small oval pellets forming the bulk. The following list of foraminifera has been kindly prepared for me by Prof. T. Rupert Jones, F.R.S.:—

*List of Foraminifera in Chalk from Taplow.*

*Textularia globosa*, Ehrenberg (common).
,, sp., angular edges (1 specimen).
,, sp., square edges (a fragment).
*Spiroplecta biformis*, P. & J. (1 specimen).
*Bolivina textularoides*, Reuss (1 specimen).
*Nodosaria radicula*, Linn. sp. (1 specimen).
*Cristellaria rotulata*, Lamarck (common).
,, *cultrata*, Montfort (1 specimen).
*Planorbulina ammonoides*, Reuss (common).
*Rotalia Beccarii*, Linn. (1 specimen. Very rare in the Chalk).
*Globigerina cretacea*, D'Orb. (common).
,, *linnæana*, D'Orb. (a fragment).
,, *bulloides*, (1 specimen).

Below both bands of brown chalk there occur some few feet of white chalk, traversed by cavities and tubes of all shapes and sizes up to an inch in diameter, and filled with the brown chalk. The top of this piped chalk is in both cases hard, crystalline, and of a nodular structure, so as to form a clearly marked floor to the soft brown chalk.

Finding that 97·7 per cent. of the brown chalk dissolved in cold

dilute hydrochloric acid, I submitted a specimen to Mr. J. Hort Player, who was kind enough to make a complete analysis of it, the result being to show that the rock consists chiefly of carbonate of lime, but contains from 18 to 35 per cent. of phosphate of lime with a little fluoride of calcium. The analysis is given in full on p. 364.

The brown colour was attributed by Mr. Player to the presence in the rock of a substance which he believed to be humic acid, and of which he extracted 1 gramme from 1000 grammes of the chalk. His identification of this acid was confirmed by the following analyses, made (by the kind permission of Prof. Thorpe, F.R.S.) by Dr. Tingle, under the direction of Prof. Japp.

"*Analyses of Humic Acid from Taplow Chalk.*

"The substance, dried at 130°, gave the following results on analysis :—

| | Analysis I. | Analysis II. | Analysis III. |
|---|---|---|---|
| Carbon ...... | 65·37 per cent. | 63·00 per cent. | |
| Hydrogen .... | 5·70 | 5·65 | |
| Nitrogen .... | .... | .... | 3·20 |
| Oxygen ...... | 20·65 | 22·63 | |
| Ash ........ | 5·08 | 5·52 | |
| | 96·80 | 96·80 | |

"The ash was coloured light red. The analyses, which were made on separate and independent portions, show that the material is not perfectly homogeneous."

Since making the analysis quoted on p. 364, Mr. Player has determined that specimens collected from the upper Brown Bed and the lower Brown Bed contain 18·6 per cent. and 35·6 per cent. of phosphate of lime respectively. A rich specimen contains about 65 per cent. of the brown grains, and the proportion of phosphate of lime in the brown grains is about 50·6 per cent.

The rock can be prepared for the microscope (1) by slicing after prolonged heating in Canada balsam, (2) by washing in water, (3) by treatment with strong acetic acid, (4) by treatment with hydrochloric acid.

(1) A thin slice of the piped chalk from just below one of the Brown Beds shows white chalk traversed by tubes full of the brown powdery variety. The white chalk contains a few scattered foraminifera, all imperfect. The test appears as a sharply defined clear layer, and encloses granular material resembling the matrix, or in some cases a crystalline substance, but in many instances is empty. Many of the foraminiferal chambers show a black cross under crossed nicols, this property being especially conspicuous in the empty forms, and being therefore presumably due to a radial structure in the test. Of this white chalk 99·2 per cent. is soluble in cold dilute hydrochloric acid. The tubes before mentioned are sharply defined and are crowded with organisms, most of them filled entirely or partly with an opaque brown material.

(2) By powdering the rock and washing in water the brown grains are readily separated from the white mud in which they are embedded. This mud has been ascertained by Dr. G. J. Hinde to consist mainly of coccoliths, discoliths, and rhabdoliths. The greyish brown sand which is left behind includes, in order of abundance, foraminifera wholly or partly filled with a brown material, hexagonal and rounded prisms broken from the shells of *Inocerami*, angular fragments of a clear amber-coloured material of waxy lustre, and little oval pellets. Rotated under crossed nicols many of the foraminifera show faint double refraction, a perfect black cross being centred on each chamber. In those which have been filled with the brown material, the terminations only of the arms of the black cross are visible in the clear layer representing the test, the brown mineral itself giving no figure. Some of the chambers are empty, as is shown by their containing a bubble of air. Others are partly filled with the doubly refracting mineral, presumably crystalline carbonate of lime, and partly with the brown material, the boundary between the two being ragged and ill-defined. The hexagonal and rounded prisms also present in part the optical properties of crystalline carbonate of lime, but have been to a great extent converted into the brown opaque material which fills so many of the foraminifera. The replacement, however, has been still more irregular owing to the absence of the confinement afforded by the cell-walls. Lastly, some of the transparent amber-coloured fragments show faint double refraction, which may, however, be merely a strain-phenomenon. Many of the brown grains, and especially the foraminifera, have a lustre resembling that of varnish. This lustre is a marked feature in all the phosphatic chalks which I have examined.

(3) Acetic acid dissolves about two-thirds of the rock, but leaves nearly the whole of the phosphate of lime, with a considerable proportion also of carbonate of lime. The residue has a marked brown colour, and is seen under the microscope to consist of those foraminifera and prisms of *Inoceramus*-shell that have been filled with or preserved in the brown material, which may be concluded therefore to be the phosphate of lime. The chambers are still surrounded by a clear layer or test, and a few show in this layer the terminations of the arms of a black cross. The contents give no reaction with polarized light. If the action of the acid is watched under the microscope, the carbonic acid can be seen escaping from the foraminifera by occasional vents, and not from the whole surface of the test. Similarly the prisms are attacked unequally, the action being confined to a spot here and there, and the final result being to give the prism an eroded appearance. A foraminifer and a prism, treated separately under the microscope with concentrated nitric acid, dissolved with effervescence, and the solution gave a copious yellow precipitate with ammonium molybdate, thus confirming the view that the residue from acetic acid consists largely of phosphate of lime.

The angular chips of amber-coloured material also survive the

treatment with acetic acid. They are of all shapes, but all sharply angular, and range from ·1 mm. to 1 mm. in length. Some consist of alternate bars of clear and cloudy material, the latter resembling the substance which fills the phosphatized foraminifera, while the clear portions show change of colour when rotated between crossed nicols. In a large number of even the smallest chips Dr. Hinde has been able to recognize bone-lacunæ, while some are fragments of fish-scales. A few have been identified by Mr. E. T. Newton as fragments of fish-teeth, the canals and lacunæ appearing as dark tubes penetrating the amber-coloured material. Other irregular markings seem to be the borings of fungi, as was suggested to me by Dr. Hinde. There seems to be no reason to doubt that the smaller chips, in which no recognizable markings occur, are also fragments of either the teeth or bones of fish *.

Several of the amber-coloured grains were picked out and treated with strong nitric acid under the microscope. A few dissolved without effervescence, but a larger number with effervescence, the action being especially brisk in the cloudy portions; the solution gave as copious a yellow precipitate with ammonium molybdate as the foraminifer and prism referred to above. This result was confirmed by the following test made by Mr. A. Dick:—Three transparent grains, on treatment with dilute sulphuric acid, became opaque with slight effervescence; the solution was evaporated nearly to dryness and a drop of water added. The clear liquor was then led off to another part of the slide and a drop of magnesia-liquor added, when the characteristic crystals of the phosphate of magnesia and ammonia were formed. When treated with dilute sulphuric acid the grains yield crystals of sulphate of lime. From these tests it may be inferred that the amber-coloured material consists essentially of a mixture of carbonate and phosphate of lime.

Lastly, the oval pellets retain their shape and appearance after treatment with acetic acid †. They range from ·3 mm. to ·9 mm. in length, and from ·2 mm. to ·4 mm. in thickness. A few show transverse markings which resemble those attributed in larger coprolites to spiral folds in the intestine. When broken across they not unfrequently disclose a darker central portion of indefinite outline, but no clear internal structure. There seems no reason to doubt that they are the excrement of small fish, plenty of which occur in the Upper Chalk. Dr. Hinde, who has given me much assistance in the investigation of these bodies, points out that they correspond in shape to bodies found by him in association with fish-remains in the interior of a chalk-flint.

Before leaving this part of the subject, I may remark that fish-remains, whether in the form of pellets or angular bone-chips, are abundant in all the phosphatic chalks yet known, and may suggest that

* Portions of a tooth of *Cimolichthys* from the Chalk have yielded chips resembling those scattered through the Taplow Chalk, and gave the same reactions with chemical tests.

† It is worth remarking that the pellets are easily sorted out by rolling the whole of the washed brown grains down a smooth inclined plane.

the concentration of the phosphate was primarily due to the action of fishes, the phosphatization of the other organisms in the rock having resulted from the replacement, more or less complete, of carbonate by phosphate of lime. The sharpness of the outline and the invariably fragmentary condition of the fish-bones suggest that they have undergone mastication by an animal possessed of grinding teeth.

Large fragments of a *Belemnitella* and of an *Inoceramus* from the brown chalk, crushed and examined under the microscope, showed the optical properties of carbonate of lime, the prisms of the latter being readily distinguishable from those which are scattered through the brown chalk. Neither the *Belemnitella* nor the *Inoceramus* gave a precipitate with ammonium molybdate. A fragment of an *Inoceramus* from the greyish chalk between the two brown bands yielded, when crushed, a number of prisms consisting of calcite, and on treatment with hydrochloric acid left a large residue of silica *. A specimen of *Echinocorys* from the brown chalk consisted of calcite. From these observations I infer that the phosphate of lime is confined to the foraminifera and to the small organic remains embedded with them.

It seems from the examination of the residue from acetic acid that the tests as well as the contents of the foraminifera have been phosphatized. In the tests the phosphate is translucent and possibly in a crystalline condition, though, from its extremely low double refraction, it does not display the black cross so conspicuously as the carbonate of lime. In the interior of the chambers, on the other hand, the phosphate has always taken an opaque form corresponding perhaps to that of the matter it has replaced, though it should be noted that many of the chambers of the non-phosphatized foraminifera are, and probably have always been, empty. In the case of the prisms the whole of the phosphate seems to be in an opaque form.

The effect of calcining the brown grains in a closed crucible at a low red heat is to blacken them all over; raised to a white heat they become white, or nearly so. When tested with phenol phthaleïn, which has the property of turning red in the presence of an alkali, the calcined grains are attacked unequally. Some assume a pink colour at once, others after several minutes, while a few, and among them many of the amber-coloured chips, show no coloration. Those which turn red are permeated by the colour in a manner which seems to indicate the presence of quicklime in every part of the grain †. This tends to confirm the inference, drawn from the behaviour of the grains when under treatment with acetic acid, that

* A section made transversely to the prisms by Mr. Dick shows that the prismatic structure is entirely wanting in the siliceous portion of the fragment. The boundaries of the siliceous portion, moreover, cut across the walls of the prisms without the slightest tendency to follow them. The silica is doubly refracting.

† I am indebted to Mr. Player for suggesting this experiment.

the phosphate and carbonate of lime composing them are intimately mixed.

(4) Lastly, when the residue from acetic acid is treated with hydrochloric acid, a large proportion is dissolved, including all the phosphate of lime, part dissolving with effervescence and part without. The residue from cold dilute hydrochloric acid consists, in the case of a rich brown specimen of the chalk, of a number of rust-coloured grains. Hot concentrated hydrochloric acid removes this colour, and becomes itself amber-coloured, at the same time evolving a bituminous smell. There remains a small number of solid, dull greenish grains, the internal casts of foraminifera, and a larger number of pellicles presenting the shapes of foraminifera in a skeleton form. The solid casts, pressed between two glasses, behave like gelatinous bodies.

The Taplow Chalk bears a strong resemblance to a phosphatic chalk which is worked in the north of France, at Beauval, near Doullens, and Hallencourt (Somme), Hardivilliers (Oise), and at Briastre and Quiévy (Nord). This phosphatic zone contains *Belemnitella quadrata*, and lies some 30 feet above the zone of *Micraster cor-testudinarium*. It may therefore be attributed to the zone of *Marsupites* (with which, moreover, it contains several fossils in common) *: that is, to the same horizon approximately as the Taplow Chalk. The Doullens deposits have been described by M. H. Lasne, from whose paper the following notes are abstracted †. The strata occur in descending sequence as below :—

Soft white chalk with flints.
Grey chalk with *Belemnitella quadrata*, with a little nodular band of rich phosphate at its base, 20 to 80 feet.
Soft white chalk without flints, occupying the position of the zone of *Micraster cor-anguinum*, about 30 feet.
Chalk (zone of *Micraster cor-testudinarium*), hard and nodular below, and with many bands of flints, about 60 feet.

The grey chalk, according to M. Lasne, consists of a white paste, with a multitude of little grains of brown phosphate of lime, all of which are derived from small organisms. M. Stanislas Meunier has shown that they are formed of an envelope of crystalline phosphates of radiate structure, generally enclosing a core of pulverulent chalk. *Globigerina*, *Textularia*, *Cristellaria*, and *Rotalia* all occur, together with some small cylindrical and rod-like bodies.

By the kindness of M. Stanislas Meunier I have been furnished with a specimen of the Beauval phosphatic chalk. The grains are

* *Belemnitella quadrata*, Defrance, *Rhynchonella plicatilis*, Sow. (var. *octoplicata*), *R. limbata*, Schloth., *Echinocorys* (*Ananchytes*) *vulgaris*, Breyn., *Cardiaster* (*Holaster*) *pillula*, Ag., are common to the Grey Chalk of Doullens and the *Marsupites*-zone of Wells (Norfolk). The reptiles and fishes of the Doullens Chalk show a closer affinity with the Norwich Chalk, which lies above the *Marsupites* zone.

† 'Sur les Terrains phosphatés des environs de Doullens, Étage Sénonien et Terrains superposés,' Bull. Soc. Géol. France, 3$^{me}$ sér. t. xviii. (1890) p. 441.

on the whole larger and darker than those in the Taplow Chalk, but they consist of foraminifera, prisms of *Inoceramus*-shell, bone-fragments, and oval pellets, and in all essential points the two deposits are identical. After treatment with acetic acid this chalk furnishes remarkably beautiful specimens of phosphatized organisms, and occasionally gives examples of internal casts in phosphate of lime of foraminifera (principally *Planorbulina*) with hair-like casts of the perforations in the test adhering.

M. Lasne notices that the proportions of fluoride of calcium and phosphoric acid are in the relation of 1 to 3: that is, in the same proportion as in apatite, from which he concludes that the mineral is a fluophosphate rather than a phosphate. The fluophosphate, as he terms it, is worked for commercial purposes in pockets of great size and depth, which it lines, generally speaking, up to the level of, but not above, the grey phosphatic chalk. The concentration of the mineral in these pockets has doubtless been due to the action of soil-water, as has been the case at Ciply in Belgium.

Scarcely less striking is the resemblance of the Taplow Chalk with that of Ciply, from which large quantities of phosphate of lime are being extracted. Though the Ciply Chalk lies above the zone of *Belemnitella mucronata*, and above the highest zone recognized in England, the close similarity of the two rocks merits more than a passing mention, especially in view of the possibility of the Taplow deposit proving to be of commercial value. The Belgian phosphatic beds were described before this Society in 1886 by M. Cornet *. They were first worked in 1870, and yielded 85,000 tons of phosphate of lime in 1884. Above the phosphatic chalk lies a tufaceous deposit (*Tuffeau de Ciply*), with a conglomerate at its base (*Poudingue de la Malogne*) which has been shown by MM. Rutot and Van den Broeck to be of Tertiary age †. The phosphatic zone includes 20 to 30 feet of coarse chalk with grey flints, which passes down into a chalk of greyish brown colour, with phosphate of lime in small brown grains. This in turn shades down into a phosphatic chalk with numerous flints, which becomes less rich downwards, until it passes into a rock formed entirely of carbonate of lime. The whole rests upon the white chalk of Nouvelles, which corresponds to the Chalk of Meudon, or the upper part of the zone of *Belemnitella mucronata*. The Meudon Chalk is correlated with the Norwich Chalk of England by M. Hébert. The greyish brown phosphatic chalk has the following composition according to M. A. Petermann, Director of the Agricultural Station of Gembloux ‡. I insert Mr. Player's figures here to facilitate comparison :—

* Quart. Journ. Geol. Soc. vol. xlii. p. 325.

† Geol. Mag. (1886) p. 10.

‡ Bull. Acad. Roy. Belgique, 2me sér. t. xxxix. (1875) p. 25.

| | Ciply Chalk. M. Petermann. | Taplow Chalk. Mr. Player. |
|---|---|---|
| Moisture | .. | ·7 |
| Organic matter | 2·83 | 2·3 |
| Lime | 53·24 | 53·7 |
| Magnesia | 0·12 | |
| Iron oxide | 1·01 | 0·1 |
| Alumina | | 0·8 |
| Potash | 0·19 | 0·1 |
| Soda | | 0·2 |
| Carbonic acid | 28·10 | 28·7 |
| Sulphuric acid | 0·89 | 0·7 |
| Phosphoric acid | 11·66 | 11·6 |
| Silica and sand | 1·96 | (Silicic acid) 0·5 |
| Fluorine | traces. | 0·7 |
| Chlorine | | traces. |
| | 100·00 | 100·1 |

M. Cornet calls attention to the large proportion of nitrogenized organic matter which the greyish brown phosphatic chalk contains, and attributes to this substance a peculiar smell evolved when the rock is treated with hydrochloric acid. In this respect also the Ciply Chalk resembles that of Taplow.

The Ciply phosphatic chalk is not rich enough to be worked at a profit in its raw state, but by simple mechanical processes, either by dry or wet methods, a product is obtained which contains from 40 to 50 per cent. of phosphate. It has also, where it has been naturally subjected to the action of soil-water, furnished a reddish-yellow powdery material, known as "rich phosphate," which occurs in pockets in the phosphatic chalk, and contains from 45 to 67 per cent. of phosphate of lime, the concentration of the phosphate having resulted from the removal of the more soluble carbonate of lime.

In hand-specimens the rich phosphatic chalk of Ciply cannot be distinguished from that of Taplow. Under the microscope, however, there are considerable differences, the brown colour and the phosphate of lime being confined to a number of generally shapeless pellets, while recognizable foraminifera are comparatively scarce, white, and non-phosphatic. The brown grains include angular chips of teeth and bone, but are more generally rounded or subangular. The chemical reactions resemble those of the Taplow Chalk.

In conclusion I may point out that there seems to be no reason why the Taplow deposit should not be as valuable as that of Ciply and Doullens (excluding the pockets), if it is not of too limited range. Both at Doullens and Ciply the richest phosphate occurs in pockets, but at the latter place the phosphatic grains are to a great extent separated from the carbonate of lime by washing. The friability of the Taplow Chalk would render it well adapted to this treatment, and the fact that the specific gravity of the phosphatic grains ranges from 2·7 to 2·8—that is, considerably above that of ordinary chalk—would facilitate their separation. It should be

noticed, however, that in the specimens examined by Mr. Player, the proportion of phosphate in the washed brown grains did not exceed 50 per cent.

Lastly, Mr. Player remarks that the phosphate of lime in the Taplow Chalk occurs in such a condition that it would not improbably serve as a valuable fertilizer in its raw state, and without undergoing conversion into superphosphate. Its condition is probably due to the incompleteness of the replacement of the carbonate by phosphate of lime in the organisms. The removal of the former leaves the phosphate in a honeycombed state, peculiarly open to the attack of soil-acids.

At present the phosphatic chalk has not been seen beyond the limits of the pit at Taplow Court Lodge. There can be little doubt that it underlies a considerable part, if not all, of the outlier of Tertiary strata on which Taplow stands, but there are no other sections to prove its extension. At the northern end of the outlier, about 400 yards west of the Rectory, flinty non-phosphatic chalk is exposed under gravel with a trace of Tertiary strata, which evidently come on in force close by. A gravel pit 300 yards west of Taplow Station also shows under the gravel a trace of Tertiary beds resting on flinty chalk of the usual character. The east-south-easterly dip of the strata about Taplow Court, if continued, would suggest that in both these cases the flinty chalk exposed may lie above the phosphatic zone. On the other hand, on the western side of the outlier, a great thickness of flinty chalk has been laid bare in the Root-House Pit, and almost certainly lies at a lower horizon than the phosphatic chalk. The lower part of the northern end of the pit exposes a nodular band resembling Chalk Rock, while one mile farther north a small pit shows a rock of the character of Middle Chalk.

The next nearest exposure of the junction of the Tertiary strata and the Chalk occurs at Pant's Hill, 400 yards north-north-east of Burnham Grove, and $2\frac{1}{2}$ miles north-east of the Lodge Pit. There the Chalk contains but one layer of flints near the top, but a pale greenish layer about 5 feet down. A thickness of about 8 feet of chalk is exposed, but none of the rock possesses the characters of the phosphatic chalk of Taplow.

Westward from Taplow, along the Great Western Railway as far as Buscomb, on the eastern slope of Knowl Hill, at Pinkney's Green, and around the Cookham-Dean outlier, the chalk is of the usual flinty character up to the base of the Tertiary strata. The same remark applies to the neighbourhood of Hedgerley, Harefield, Rickmansworth, and Watford, one of the sections at Harefield giving an open view of the topmost Chalk to a depth of at least 60 feet below the Reading Beds.

The evidence therefore tends to show that the phosphatic chalk is of strictly local occurrence. Its disappearance may be due either to its passing into chalk of the usual type, or to its being overlapped in every direction by Tertiary beds. A fact which tells against the former supposition is that we have not seen any chalk approaching

the phosphatic type in any of the pits around Taplow, as might have been expected were there a transition from the one type of chalk into the other. On the other hand, if the phosphatic chalk is overlapped in every direction by Tertiary beds, there must be a more rapid transgression than is known elsewhere in this part of England. The scarcity and incompleteness of the sections, however, preclude our forming a definite opinion as to the reason of our failure up to the present to detect the deposit in other parts of the neighbourhood.

In conclusion, I wish to express my thanks to Mr. Player for his analysis, and for many valuable suggestions as to the treatment of the rock, and to Prof. Thorpe for his determination of the humic acid. To Dr. Hinde, Mr. Teall, and Mr. Dick also I am indebted for much assistance in the examination of the chalk under the microscope.

*Note.*—A month after this paper had been read, I received a proof of a communication made in February to the Royal Academy of Belgium by MM. Renard and Cornet, and thus learnt for the first time that they had been engaged in an exhaustive microscopic examination of the phosphatic chalks of the Continent *. It was a pleasure to me to find that my observations on these rocks, which were carried only so far as to enable me to institute a comparison between the English and Continental chalks, are in the closest possible accord with those of MM. Renard and Cornet. The fact that the MS. of my paper had passed out of my hands before the publication of their results accounts for my not having acknowledged in the foregoing pages their priority in many important observations. Among these I may mention the recognition of fish-remains in all the known phosphatic chalks.—(May, 1891.)

## EXPLANATION OF FIGURES.

(Figs. 2, 3, 4, 5, and 6 by transmitted light.)

Fig. 1. Coprolites, selected to show the transverse markings attributed to the intestinal folds. One contains a prism from the shell of an *Inoceramus*.
2. Fragment of bone, showing lacunæ.
3. Fragment of bone, showing lacunæ; from Dr. Hinde's specimens.
4. Fragment of bone, bored by a fungus or alga.
5. Fragment of a fish-scale.
6. Fragment of a fish-scale, bored by a fungus or alga; from Dr. Hinde's specimens.

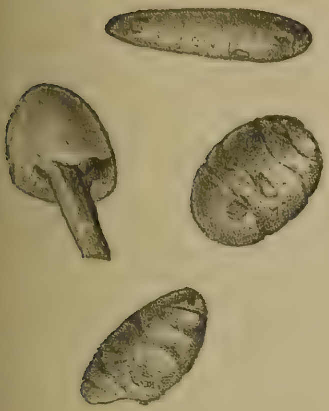
(Figs. 2, 3, 4, and 5 were photographed from drawings by the Author.)

## Discussion.

Dr. G. J. Hinde said that he had examined microscopically the phosphatic chalk of Taplow, and compared it with the similar material from Doullens and Ciply, and he fully agreed with Mr.

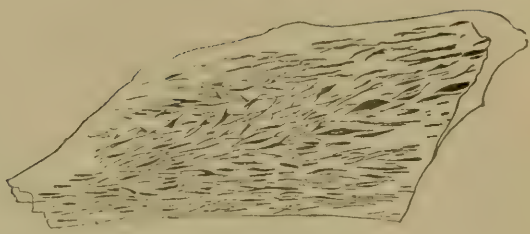
* 'Recherches micrographiques sur la nature et l'origine des roches phosphatées,' Bull. Acad. Roy. Belgique, 3me série, t. xxi. (1891) p. 126.

Fig. 1.



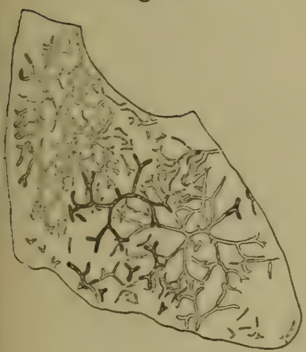
× 20 diam.

Fig. 2.



× 70 diam.

Fig. 4.

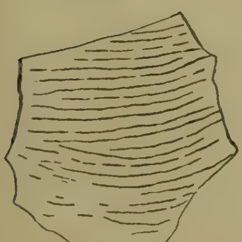


× 70 diam.

Fig. 3.

× 120 diam.

Fig. 5.



× 60 diam.

Fig. 6.

× 160 diam.

FISH-REMAINS FROM TAPLOW CHALK
(after treatment with acetic acid).

Strahan's description thereof. The fine, white, powdery portion of the Taplow rock consisted nearly entirely of coccoliths, discoliths, and rhabdoliths, unaltered, and of carbonate of lime similar to those in the normal white Chalk. The minute, translucent, angular fragments in the granular portion were shown to be pieces of fish-bone by the occurrence in them of true bone lacunæ and canaliculi, and many were likewise thickly penetrated by borings of algæ or fungi. Similar fragments were present in the Doullens and Ciply material, but their osseous nature had not previously been recognized. The minute phosphatic pellets were probably coprolites of small fishes. The evidence pointed to the exuviæ of fishes as the source of the phosphatic materials in these deposits.

Mr. Whitaker said that, from the regularly bedded character of the phosphatic chalk, one would have expected it to occur for some distance from the pit; but no trace could be seen either of the phosphatic beds or of the flintless Chalk in which they occur. It seems as if the topmost Chalk here occurs only over a small area, having been eroded elsewhere. That this was the case to the west and north-west had been surmised by Mr. Jukes-Browne ("Geology of London," vol. i. pp. 76-78, 1889), from an examination of fossils collected from the various pits; but the thinning-out of the top Chalk seems to be more sudden than was expected, and not only in the above directions but all round from Taplow. Mr. Strahan's discovery showed how much there might remain to be done, even with regard to so well-known a formation as the Chalk.

Prof. Judd remarked upon the interesting nature of the microscopic borings described by Dr. Hinde. His attention had been of late directed to the subject in studying oolitic grains, both recent and fossil. Both Mr. G. Murray and Dr. Scott were of opinion that these borings in shells were produced by the plants that had been so well described by the distinguished French phycologist, Bornet. A very acute observer, Mr. F. Chapman, had noticed that shell-fragments in the Gault frequently exhibit these borings, and Dr. Scott had been able to identify several of Bornet's genera, founded on recent specimens, as being represented in these Cretaceous shells. Bornet believed that these boring algæ perform a very important part in the economy of nature, by bringing about the destruction and solution of shell-fragments.

The President, alluding to the geological and economic interest of the discovery described in the paper, remarked that though the area occupied by the phosphatic layers seemed to be small, there was good reason to hope that somewhere else in the Upper-Chalk districts the same or similar bands might yet be found. The search for such deposits would now be stimulated by the information so fully supplied by the Author, who himself would no doubt follow up his observations at Taplow by a thorough examination of the higher members of the Chalk in the East of England.

## 22. Manod *and the* Moelwyns. By A. Vaughan Jennings, Esq., F.L.S., F.G.S., Curator of the Eton-College Museum, and Griffith J. Williams, Esq., F.G.S. (Read March 11, 1891.)

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### I. Introduction.

On the north and west of the great mass of Harlech Grit which forms the centre of the Merioneth anticlinal, the Lingula and Tremadoc strata dip under the mountains of the Moelwyns and Manods, and are there overlain by the Arenig ashes and slates. The beds exposed on the southern slopes of these mountains have therefore the same general stratigraphical age as those cropping out on the northern slopes of Cader Idris and on the western aspect of Arenig and the Arans.

The general relations of the rock-masses of this difficult district have been admirably elucidated by the officers of the Geological Survey, and the results of their work published in Sir A. Ramsay's invaluable memoir on the Geology of North Wales.

In the present paper, which is the result of observations carried on interruptedly for several years, our objects are :—

To offer conclusive evidence as to the intrusive nature of the great crystalline mass known as the Syenite of Tan-y-grisiau.

To correct what seems to us an inaccuracy of some importance in the correlation of beds in different parts of the range, as interpreted in the map and memoir of the Geological Survey.

To trace with greater completeness the position and constancy of the beds of slate in the Arenig series ; a subject of considerable local and practical importance, when we remember that those who are engaged in slate-quarrying have so far had to rely mainly on their personal and unaided observation.

In order to make the conclusions arrived at on these points more readily intelligible, the writers have worked over all the ground from Dduallt on the south to Tal-y-waenudd * on the north, and from Moelwyn Mawr on the west to Manod on the east, inserting the geological details on the six-inch Ordnance-Survey map. The structure of the Moelwyn range itself is illustrated by a series of

* Spelt 'Tal y Waunedd' on the map.

three sections, through Moelwyn Mawr, Foel Rydd*, and Craig Nyth-y-Gigfran.

## II. Topography of the District.

The area under consideration is bounded on the west by the Moelwyn ridge, the strata of which strike S.W. to N.E. from the slopes overlooking Llanfrothen to the Cwm-Orthin valley, and are continued on Craig Nyth-y-Gigfran to the broken country behind Blaenau Ffestiniog. Here the series is fractured by several great faults with a downthrow to the south and east, so that strata once continuous with those of Moelwyn now form first the black and broken mass of Gareg Ddu, and then the rounded hills of Manod Mawr and Manod Bach on the east. On the latter side the strike is more nearly S.E. to N.W., the outcrops meeting those of the Moelwyn side near Tal-y-waenudd. The general strike for North Merionethshire is east and west, so that in the disturbed region round Ffestiniog we have a sharp local deflection to the north.

Filling up the triangular area thus formed, lies the long rounded. Moel Tan-y-grisiau, a mass of crystalline rock, to the intrusion of which the peculiarities of the district seem largely due.

## III. Succession of Strata on the Moelwyns.

For a geologist wishing to study the rocks of this district in consecutive order, the best plan is certainly to begin with the Moelwyn range itself, where the strata are least disturbed.

Looking at the mountain from some position on Moel Tan-y-grisiau, the east face of it is seen to consist above of upper and lower tiers of steep, rugged, cliff-like escarpments of the Arenig igneous rocks, and below of a series of step-like ridges and grassy slopes due to the unequal weathering of the Tremadoc beds.

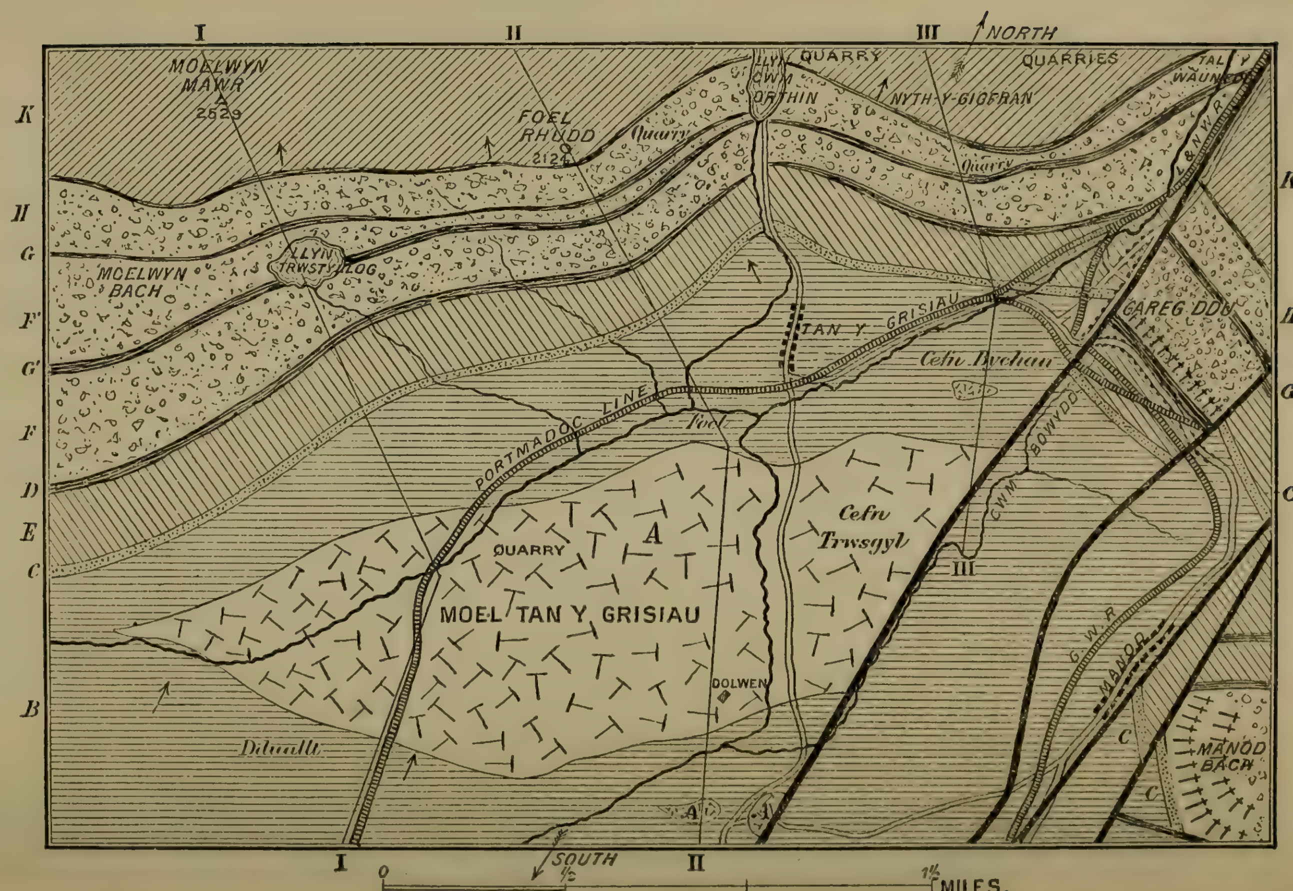
At the southern end, Moelwyn Mawr, the highest point, stands back behind the general escarpment, overlooking the deep hollow of Trwstyllog with its lonely lake. From it, the ridge descends for a time, but reascends to Foel Rydd at the northern extremity, overlooking the valley of Cwm Orthin.

The first section accompanying this paper runs through Moelwyn Mawr, the second just to the north of Foel Rydd. Along either line the ascent may be made without difficulty and the order of the strata observed.

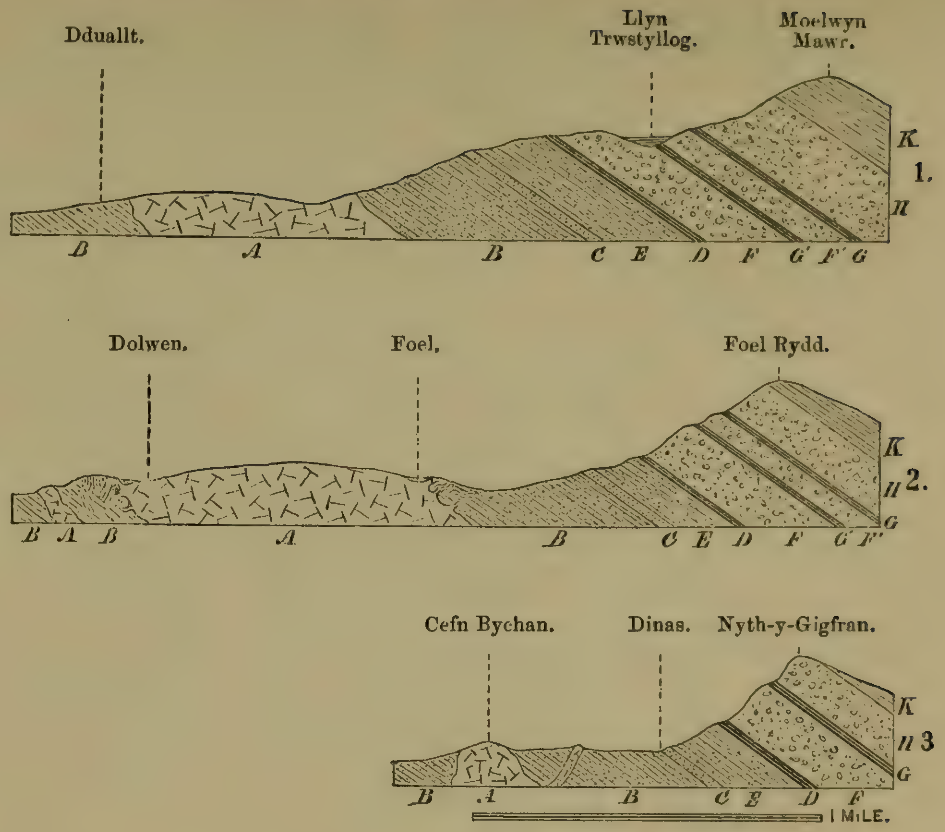
(a) *The Tremadoc Series* lies partly below but mainly above the intrusive mass of Moel Tan-y-grisiau. While the black slates which commonly constitute the lower part of the series may be seen unaltered about Dduallt and near Pengwern, the upper part is in the Ffestiniog neighbourhood changed into hard spotted schistose or flaggy rocks. Immediately at the margin of the granite there occurs a hard compact rock showing no trace of bedding or cleavage. Under the microscope it is seen to consist of finely crystalline particles,

* Spelt 'Moel y rhudd' on the Survey map.

MAP OF THE MOELWYN DISTRICT.



## Sections of the Moelwyn Range.

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among which are distributed specks of green mica. It is in fact a typical *hornfels* *, such as commonly marks the junction of large masses of intrusive rock with beds of slaty character.

The lower slopes of the mountain consist, on the line of the first section, of somewhat similar rock, but with distinctly bedded appearance and unequal weathering. Higher up, definite spots appear, and weather out on exposed surfaces ; in some cases the spots are so numerous that the intervening laminæ curve over and under them, so that the appearance is like that of a spherulitic lava.

Towards the north, round Tan-y-grisiau and under Blaenau, the rocks are pale-coloured with green spots and have a remarkable flaggy structure, splitting into thick slabs with smooth faces. Though regarded by Sir A. Ramsay as due to bedding, this would seem to be rather a cleavage-structure, as the slabs dip at the same high angle as the cleavage of the true slates above. Moreover, the bedding is frequently seen in the same masses as the cleavage, making an angle of 15° with it.

In some parts the spotted flags contain remarkable concretions—spherical bodies reaching a diameter of two or three feet, showing a rough concentric structure on weathering, and largely calcareous in composition. They are well seen at Tai Matthew (between Glan-y-pwll and Tan-y-grisiau) and at Clos-y-graig.

Examined under the microscope these rocks also appear to consist of crystalline particles, green and white microliths † with magnetite-dust being disseminated throughout. The white microliths lie in all directions and frequently form radiating groups round the magnetite crystals ; they are lath-shaped or acicular, and polarize distinctly in colours. Probably they are developing micas. The green material is scattered through the sections in aggregations of granules, which are almost isotropic, but seem to be of chloritic nature. It is commonly the absence of the green material in patches that gives rise to the spotted appearance, the dark areas in reflected light being the transparent ones in sections. In the centre of these lighter areas there is, however, almost always a nucleus of the green mineral. The nature of the spots in these rocks is therefore somewhat different from that of typical "spotted slates," where the appearance is due to local aggregation of the darker minerals.

In spite of the intensity of the metamorphism and the immense thickness of rock affected, there is a striking absence of distinct crystals. The brown mica so common in areas of contact-alteration is absent throughout. In some cases, as Prof. Cole pointed out to us, the spots have, however, a tendency to quadrilateral form, and may perhaps be embryo crystals of andalusite ; but there is nothing in any way similar to the rocks of the altered region about Skiddaw.

* Teall, 'British Petrography,' p. 373 ; Rosenbusch, 'Die Steiger Schiefer,' Abh. z. geol. Specialkarte v. Elsass-Lothr. vol. i. Heft ii., Strassburg (1877).

† We have used the term 'microliths' on account of the general appearance of the rock. Most of them, when observed between crossed nicols, prove to be crystalline, but not all.

As regards the original nature of these rocks, it is difficult to speak with certainty. The whole series, from the granite to the Arenig agglomerates, is described on the Geological-Survey Map as "Felspatho-calcareous, flinty and slaty ashes, often talcose" *; and this description is retained in the later editions, in which, owing to the insertion of the Garth Grit, the greater thickness of them is seen to belong to the Tremadoc group. On the other hand, in the later editions of the memoir, Sir A. Ramsay still holds the opinion that ashes do not occur earlier than the Arenig period, and states that on re-examining these rocks he concluded they were only the ordinary sediments of the district greatly altered †. Considering the difference between them and altered slates, it seems to us more natural to regard them as having been mainly composed of fine ash, or of mixed ashy and sandy materials. Such a conclusion would be in harmony with the result of observations on Cader Idris ‡.

The generalization that the Lower-Silurian igneous rocks are confined to the Arenig period does not seem to be tenable in detail. Just as the ejection of ashes continued in the earlier Llandeilo period, so there seems no reason to suppose that the process may not have commenced in Tremadoc times. It may be objected that if these rocks are traced round the south of Moelwyn towards the west, they pass into the ordinary slates of the Llanfrothen area; but seeing that the point at which they disappear is the point at which the whole agglomerate-mass above also thins out entirely, the fact is rather in favour of our view than against it. It must, however, be confessed that microscopic study gives no evidence of an originally ashy composition.

(b) *The Garth Grit*, which on palæontological evidence has been regarded as forming the base of the Arenig series, is found below Moelwyn Mawr at a height of 1300 feet, and, though repeatedly displaced by minor faults, can be traced northwards towards Blaenau. The main mass is about 13 feet thick, but for several feet below there are thin bands of grit among the schistose rocks, showing that the change of conditions was not altogether a sudden one. Microscopic examination shows the grit to be made up of large quartz-grains with a slight admixture of felspar, and a little green mica between the grains. The appearance of the quartz suggests its derivation from granitic rocks, though not of necessity directly; indeed, it seems most probable that it is derived from the older Cambrian grits.

Like the rocks above and below, the grit has been altered by metamorphism. It is much more compact than in the locality where it was first observed; so much so that it might fairly be termed a quartzite, and its appearance under the microscope would give it a greater right to that name than is the case with other Palæozoic grits, such as that of the Stiper Stones.

Above the white grit there is in parts a thick band of a dark-

* Ramsay, 'Geology of North Wales' (1881), pp. 25, 88, &c.
† *Ibid.* p. 87.
‡ Cole and Jennings, Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 436.

green-coloured rock, which seems also to be a grit. In this the grains are more angular, there is a larger proportion of felspar, mica, and magnetite, and garnet is also present.

(c) *The Arenig Series.*—The beds immediately above the grit do not differ greatly from those below. They still consist of spotted rocks with a flaggy structure. In some cases there is a well-developed "secondary cleavage" or "pillaring" at right angles to the bedding and directed 13° W. of N., as in the slate quarries above. So distinct is it that these beds are quarried when large straight-edged slabs are wanted, blocks of fifteen feet in length being easily obtained. Beds of fine ash also occur in this level, and north of Cwm Orthin they form a considerable local thickening of the strata between the grit and the agglomerates. At this point they appear as a hard, very light-coloured rock, spotted with white, and sometimes finely banded. Though different in appearance from the spotted flags below, this rock has much the same structure, being made up of fine colourless crystalline particles with disseminated chlorite. The white spots might be taken at first for developing crystals, but when they are seen under the microscope this is found not to be the case.

Above, there seems to be an increasing proportion of clayey material, and a blue colour in the rocks appears, increasing until the first bed of true slate is reached. This, the "Lower Slate Bed" as we propose to call it throughout in this paper, consists of an impure slate, often sandy and ferruginous, which has never as yet paid for working. Trial levels may be seen repeatedly along Moelwyn, as also under Gareg Ddu and Manod Mawr. It has not yielded fossils on the Moelwyn Range, but a *Lingula* and *Orthis Carausii* have been found in it at Cae Clyd, and a *Tetragraptus* south-east of Manod Mawr. It is interesting to note that the slate bed is covered in places by a fine-grained, grey rock, similar to the "hards." of the Llandeilo quarries, which we hope to examine in greater detail at some future time. Just at their junction occurs a grit band a few inches thick, full of ovoid black "pebbles;" it is very similar to the bed mentioned by Messrs. Cole and Holland * as occurring on Rhobell Fawr, and regarded by them as equivalent to the Garth Grit. It would be rash to say that the two beds are equivalent, especially as we have only observed that on Moelwyn at one spot, but the fact that there are several minor grit bands above the true "Garth Grit" is worth the notice of geologists in North Wales. Another feature of interest is that the black "pebbles" in this bed show under the microscope a number of "oolitic" grains with concentric structure, recalling at once the appearance of the Arenig ironstone of other localities.

The igneous rocks of the Arenig series have been regarded as consisting of felstones and agglomerates; an upper and lower felstone alternating with upper and lower agglomerates. Closer examination shows that the succession is by no means uniform in

* Cole and Holland, Geol. Mag. (1890) p. 449.

different localities, and that the name "felstone" has covered a considerable variety of rocks. To keep, for the present, to Moelwyn alone, we cannot accept the mapping of the greater part of the igneous group as felstone; we find that the rocks deserving that name in the terminology of the field-geologist are very thin in proportion to the fragmentary strata. The whole thickness of igneous rocks can be divided into Lower, Middle, and Upper Agglomerates, separated from one another by slate beds; at the base of the lower there is found a thin band of felstone, and in the middle of the upper, one of considerably greater importance.

The rock we term "felstone" has a fine compact greenish base without porphyritic crystals. On weathered surfaces it shows the smooth opaque white crust peculiar to highly silicated rocks. In parts, as in the thick bed below Foel Rydd, there is a well-marked columnar structure, somewhat remarkable for the more rapid weathering of the interior of the columns, producing deep hollows in the top of the columns, and partly hollow centres when seen in longitudinal section. There is no evidence in favour of regarding this rock as intrusive, and, on the other hand, microscopic examination shows none of the characteristic structures of a lava. It seems far more probable that we have to deal here with a fine compacted ash; and this view is very strongly supported by the close similarity apparent between the "felstone" and the matrix of the agglomerates.

Sir A. Ramsay considered that all the felstones of the district were contemporaneous lavas, and he based his conclusion partly on the presence of a "flow-structure" in places, but mainly on alteration observed in the lower slates. The former character is not of much value in determining origin, because, as is pointed out in the memoir, appearances indistinguishable from flow-structure are seen in some of the bedded rocks below, and also in the agglomerates. As regards the latter argument, it is probable that the development of spots in the Lower Slate is due to the metamorphic forces that have so altered the rocks below and up to it. On the other hand we have seen with great distinctness the junction of the Upper Felstone with the slate below, and found no evidence of alteration.

The agglomerates may be divided, as we have said, into Lower, Middle, and Upper beds, especially at the southern end, along the line of Section 1 (see p. 371). Northwards, the Middle bed thins out at the Cwm-Orthin Valley; while the others form the two cliff-like walls whose detached blocks have covered the mountain-side. The groundmass is compact and light-coloured, closely resembling the felstone in appearance; on protected surfaces, joint-faces, &c., it may indeed be difficult to distinguish the two rocks, but on weathered faces there can be no doubt as to the clastic character of the agglomerates. Rounded pebbles and angular fragments of stratified rocks are heaped together in every direction. In some places the embedded rocks are of great size; one in the Upper bed was found to measure 11 feet in length by 4 in width.

It is interesting to note that there occur in the Upper Agglomerate

fragments of slate with distinct cleavage, and containing *Lingulæ*, indicating that older aqueous rocks had already undergone pressure and alteration before the later Arenig eruptions. In the Middle Agglomerate about Llyn Trwstyllog, where the base is bluish and full of porphyritic felspars, there occur indefinite slaty patches which seem on the other hand to have been ejected in a soft condition, as in the tuffs on Cader Idris.

Of the rocks contained in the agglomerates we have made no detailed study; but they are for the most part slaty and schistose fragments mixed with rounded pebbles of fine-grained "felstone."

It will be noted that the igneous rocks are of acid composition throughout, and there is not that transition from basic eruptions below to acid lavas above which is so marked on Cader Idris.

The Middle-Slate bed runs under the lake of Trwstyllog and up towards Moelwyn Bach; its course across the Cwm being traceable by the succession of trial-levels, and the low ground it forms between the harder rocks above and below. Northwards, it forms the strip of marshy land lying above the Lower Agglomerate, and can be traced along to the Wrysgan Quarry on the line of Section 2 (see p. 371). In spite of the high angle of dip, the quarry is still worked, though the quality of the slate is not so good as that of the Llandeilo beds, owing to hardness and coarseness below, and the presence of sandy bands in the upper part.

The Upper-Slate bed runs round Cwm Trwstyllog, above the lake, and has been worked on the south-west side of the hollow. Traced northwards it seems to descend towards the Middle-Slate bed, owing to the thinning of the Middle Agglomerate. This does not disappear entirely as represented in the Survey map and memoir. A short distance beyond the marshy ground, where it seems lost, the Upper-Slate bed reappears and can be traced along under Foel Rydd, where it is represented on our second Section above the Wrysgan Quarry. Between the quarry and Cwm Orthin, the Middle Agglomerate thins rapidly, resulting in the approximation and coalescence of the Upper- and Middle-Slate beds.

(d) *The Llandeilo Series.*—Lying on the Upper-Agglomerate series come the slates which we regard as of Llandeilo age, dipping westward toward Cynicht. They form the top of Moelwyn Mawr and Foel Rydd, but have been removed from Craig Nyth-y-Gigfran.

Immediately above the Upper Agglomerate at Llyn Bowydd occur graptolites identified by Prof. Lapworth as *Climacograptus Scharenbergi* and *Didymograptus Murchisonii*, var. *bifidus* (Hall), which are typical Llandeilo forms. Apart from other evidence, Prof. Lapworth, who has kindly examined the specimens, regards the Llyn-Bowydd fossils as belonging "to the highest zone of the Skiddaw Slates or lowest beds of the Llandeilo."

At Ty Obry, in strata certainly not higher in the series, are found *Climacograptus cælatus*, Lapw., and *Diplograptus dentatus*, Brongn.

## IV. Correlation of the Strata.

After examining the succession of strata as seen on the mountain-side under Moelwyn Mawr or Foel Rydd, the geologist would naturally turn his attention to the outcrops north of Cwm Orthin, in order to make sure that the beds so far observed are continuous.

Direct observation in the valley itself is difficult, and for the most part impossible, owing to the enormous accumulation of slate-rubbish from the quarries above. There is, however, no indication of faulting or dislocation of the strata, and the Garth Grit is found in its natural position on either side of the valley. On Moelwyn, as already noticed, the upper and lower igneous masses separated by the slate correspond to well-marked physical features on the mountain-side; and the reappearance of those features on Craig Nyth-y-Gigfran, which continues the range to the north, at once suggests that the strata correspond on the two sides of the valley.

On examining the Geological-Survey Map, on the other hand, it will be seen that the *lower* igneous beds of Moelwyn are marked as crossing *upward* across Cwm Orthin and forming the *top* of Craig Nyth-y-Gigfran, while the upper agglomerates of Moelwyn and lower agglomerates of Nyth-y-Gigfran thin out suddenly at the same place. This could only be the case if there existed a fault, with a downthrow to the south of more than 600 feet, along the Cwm-Orthin valley; but the presence of such a fault has never been suggested, and is, in fact, disproved by the continuity of the Garth Grit. Moreover, this interpretation would make the Lower-Slate bed of Moelwyn the equivalent of the bed worked at the Nyth-y-Gigfran Quarry; and owing to the variation in quality of the different slate-beds, the question becomes one of considerable local and practical interest.

Reference to the Survey Memoir shows that it is not a question of mis-drawing of the lines on the map, for the map embodies the opinion of the surveyors. Sir A. Ramsay states that the "porphyry abutting against the fault at Tal-y-waenudd" (that is, the upper igneous series) "crosses the valley of Cwm Orthin a little below the lake and rests directly on speckled flags of the Arenig beds" *.

In order to discover what evidence there was to support this view, we have carefully examined the cliffs between Cwm Orthin and Tal-y-waenudd, and made a section of them passing through the Nyth-y-Gigfran Quarry, for comparison with those farther south. We find that the Lower-Slate bed of Moelwyn occurs here in its natural position; that is, it is lower than below Foel Rydd, owing to the northerly dip. It is not represented on the map, but lies at the bottom of the Lower Agglomerate, which is doubtless the same as the Lower Agglomerate on Moelwyn, and, like it, contains a felstone band at the base.

On the other interpretation this Lower Agglomerate not only thins out suddenly at Cwm Orthin, but disappears inexplicably at the fault on the north, and cannot be correlated with any beds except the "Lower Ashes" on the farther side of Arenig.

* Ramsay, *op. cit.* p. 94 and footnote.

In the same way the Nyth-y-Gigfran slate-bed is obviously the same as that worked at Wrysgan (the Middle-Moelwyn bed), or a coalescence of that and the narrow band above (Upper-Moelwyn bed), owing to the thinning out of the Middle Agglomerate. The Upper Igneous series, over the Nyth-y-Gigfran Quarry, corresponds to that over the Wrysgan Quarry, but the felstone is less in thickness.

We find in fact that the strata north of Cwm Orthin can be correlated with those south of it, in consecutive order and without involving the difficulties raised by the interpretation given on the Geological-Survey Map.

Proceeding farther northwards, the escarpment of the igneous rocks is seen to dip downwards towards the railway-tunnel and the road to Dolwyddelen. There is a curious break in continuity of the upper series for a short distance just south of the conspicuous rock known as Craig Flaen Llym, owing to which the Upper-Slate bed seems to come into contact with the Llandeilo slates above. It is also of importance to notice that the upper series becomes entirely ashy, while in the lower there is a development of a grey felstone.

The great Ffestiniog and Trawsfynydd fault cuts through the strike just to the east of the railway, so that the continuation of the strata under consideration has to be looked for in Gareg Ddu, half a mile to the south.

Thus the Garth Grit is found altogether south of Blaenau Ffestiniog, to the N.E. of Cwmbowydd, and the Lower-Slate bed appears by the side of the High Street.

Gareg Ddu itself consists below of grey felstone like that of Manod, columnar in parts. It corresponds in position with the Lower Agglomerate of Moelwyn, and though coloured as felstone on the map, its upper portions consist entirely of agglomerate. Along a strip of marshland behind runs the equivalent of the Upper-Slate bed of Nyth-y-Gigfran, covered as before by an upper agglomerate. It is this latter bed that we regard as equivalent to the "Upper Ashes" of Arenig, and not the thin band occurring here, as at Foel Rydd, in the Llandeilo slates above *.

Bounding Gareg Ddu on the east is another fault with downthrow to the west: that is, the Gareg-Ddu mass lies in a "trough" between the lines of fracture. The strata with which its east side was continuous lie just outside the sketch-map accompanying this paper, and occupy a small area between this fault and the next. The greatest fault in the district is that which, running along the east side of this area, has thrown down to the south the mass forming Manod Mawr and Manod Bach.

Thus the Garth Grit, last seen above the road near Plas-isaf, appears again behind Manod School.

Above it occur the spotted flags with the secondary cleavage referred to as found near Tan-y-grisiau; and a little higher a bed of slate, evidently the same as that at the foot of Gareg Ddu. The

* Ramsay, *op. cit.* p. 95.

felstone above is here at its maximum thickness, about 1500 feet. In character it resembles that of Gareg Ddu in its grey colour, columnar structure in parts, and slaggy appearance, but it is more porphyritic. Under the microscope it is at once seen to differ from the Moelwyn felstones, and is apparently a true igneous rock, probably contemporaneous. An imperfect spherulitic or granophyric structure is present.

The strata which formerly covered the felstone on the Manods have been denuded away from the top; but owing to faults they are found "troughed in" behind, in the area round the Graig-ddu Quarries, and consist there of agglomeratic rocks like those above Blaenau Ffestiniog itself.

## V. The Intrusive Rocks.

The intrusive rocks belonging to the Ffestiniog district are, with the exception of the Tan-y-grisiau granitite, few and unimportant.

Between Trawsfynydd and Arenig there are several patches of "greenstone" breaking through the Lingula Flags. As suggested by Sir A. Ramsay, these may bear the same relation to the Arenig eruptions that the plutonic masses of Cynicht and Moel Siabod have to those of Bala age. We know of none of this series as occurring within the area under consideration.

The greenstone near the top of Moelwyn belongs to the Llandeilo series. It is a typical diabase composed of augite, plagioclase, and viridite, with much magnetite; but though it comes into the Moelwyn area, further consideration of it may be left until the rocks between Ffestiniog and Snowdon can be dealt with together.

In the Arenig series there are a few dykes cutting through the already metamorphosed strata; those on the Cwm-Orthin incline, below the Oakley Quarry, and in the mass of Gareg Ddu may be mentioned as examples. There is nothing worthy of notice in the rocks themselves, which are considerably altered andesitic intrusions. The spotted flags in contact with them are often metamorphosed to a very compact, mottled brown and green porcellanite with a peculiar lustre.

The mass of rock known as Moel Tan-y-grisiau, which lies between Ffestiniog and the Moelwyns, would strike almost any observer as differing from the surrounding strata. Its rounded form contrasts as strongly with the rugged and broken outline of the Moelwyns as does its covering of purple heather with the cold greys and greens of the surrounding hills. Mapped by the Geological Survey as "Intrusive Syenite," it has since become better known owing to its inclusion by Dr. Hicks in his list of the pre-Cambrian rocks of the British Isles *. Dr. Hicks at the same time expressed his belief that Mr. Tawney had "most satisfactorily proved that it is mainly of Dimetian age." This view has not been widely adopted, and the

* Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 304. In the Description of the Geology of North Wales, written by the same author for the International Geological Congress of 1888, it was not, however, included in a similar list.

intense metamorphism of the surrounding rocks would be a great obstacle to its acceptance, even were more direct evidence unobtainable. For any observer who has gone carefully round the border of the crystalline mass there can remain no doubt as to its intrusive character. [At the meeting at which this paper was read we exhibited photographs clearly showing the intrusion at more than one point.]

In the neighbourhood of Dolwen on the east side and of Foel (near Tan-y-grisiau) on the west, not only are the Tremadoc rocks in contact with it broken and twisted into sharp contortions, but veins of the molten rock have penetrated the strata in all directions, carrying up detached fragments along with them. Lying between the granite and Coed-y-Cribau is a small hill at Cymerau Uchaf, which is composed of displaced Tremadoc rocks now in a vertical position; while near Cefn Bychan there is a vein of the intrusive rock breaking through higher slate-beds at a distance of $\frac{1}{4}$ mile from the main mass.

Round the junctions the sedimentary rock is altered into a compact *hornfels*, and in some places it is very difficult to distinguish the altered rock from the finely crystalline edge of the granite.

The rock itself varies from grey to reddish-brown, and is remarkable in all parts for the abundance of quartz, which causes weathered surfaces to appear like those of a grit. This and the felspar, which becomes red on decomposition, are the chief constituents, so that in some parts the name of "aplite" might be used. Grains of darker mineral are, however, usually present, and segregation-patches of these are very common. Narrow veins of a dark mineral frequently occur, and are often numerous and roughly parallel, giving to small fragments a somewhat gneissic appearance. In cavities there occur crystals of chlorite.

Under the microscope the most noticeable feature is the appearance of crush and strain seen in the broken and granular quartz. It is this appearance that has suggested the comparison of the rock with that of Bryn-y-garn *, near St. David's. The quartz occurs in irregular grains, often intergrown with the felspar so as to form a distinct "graphic" structure. In many cases it surrounds the other minerals and is evidently secondary.

The felspar is very much altered, but the cleavage is usually distinct. Twinning, when shown between crossed nicols, is commonly repeated; it is, therefore, probable that the felspathic constituent of the rock is oligoclase, with perhaps a certain proportion of soda-orthoclase.

The dark minerals prove to be biotite and chlorite. The thin black-looking veins consist of a brown biotite, evidently secondary, with a strong fibrous appearance.

Chlorite is common in grains throughout, and in cavities often forms large crystals (hexagonal prisms with basal plane).

In a description of the great eurite of Cader Idris, it has been

* Teall, 'British Petrography,' p. 319.

suggested by Messrs. Cole and Jennings * that the Tan-y-grisiau "syenite," "with its abundant quartz and its poorness in ferro-magnesian silicates, is just such a rock as might have resulted had more complete crystallization, under slower conditions of cooling, taken place in the eurite of Cader Idris."

Through the kindness of Mr. L. W. Fulcher, B.Sc., who has made an analysis of the Tan-y-grisiau granitite, we are able to show that that suggestion was justifiable. The silica percentage is rather higher in the Tan-y-grisiau rock, but the two analyses present on the whole a remarkable agreement:—

| | *Tan-y-grisiau Granitite.* | | *Cader Idris Eurite.* |
|---|---|---|---|
| $SiO_2$ | 75·02 | | 72·79 |
| $Fe_2O_3$ | 2·89 | | 3·32 |
| $Al_2O_3$ | 12·88 | | 13·77 |
| CaO | 1·17 | | 1·94 |
| MgO | ·32 | | ·62 |
| $K_2O$ | 5·03 | | 2·99 |
| $Na_2O$ | 3·28 | | 4·12 |
| $H_2O$ | ·60 | Loss on ignition... | 1·08 |
| | 101·19 | | 100·63 |

That the intrusion of the granite is subsequent to the hardening and cleavage of the Tremadoc rocks is shown by the fact that angular cleaved fragments of the latter lie, in all directions, in the offshoots of the crystalline mass. As the cleavage of the Tremadoc beds is similar to that of the overlying strata, it would seem probable that the date of the intrusion of the granite is later than the period of consolidation of the Llandeilo rocks, and that it has therefore no immediate relation to the Arenig eruptions.

Such questions as this can, however, only be decided by a wider study of the country as a whole; and for the present we prefer to leave our record of observations in the Ffestiniog district as it stands, without burdening it with theories that may be premature.

## Discussion.

Prof. Hughes bore testimony to the excellent work being done by Mr. Williams in the Ffestiniog district. He thought that possibly the extension of the syenitic mass at a small depth below the surface would account for the metamorphism of the rocks so far from the area where it is now exposed, and that the presence of more felspathic material in the sediment had caused some beds to lend themselves more readily to the kind of metamorphism noticed. The earth-movements which resulted in the Merioneth anticlinal had crushed this unyielding mass of then solid intrusive rock among the more yielding sedimentary strata so as to produce the disturbance of the beds observed along its flanks. He had not himself

* Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 438.

seen evidence of the occurrence of *cleaved* Cambrian rocks in the agglomerates. He criticized the view that the Portmadoc Grit could be traced as shown on the new Survey-Map at the base of the Arenig all along the Ffestiniog district, and explained that east of Garth it was split up by the intercalation of shale; that its representative consisted of less quartz and more felspathic material near Tanybwlch; while farther east it was difficult to identify it at all.

Dr. Hicks congratulated the Authors on the important results obtained by them in their investigations in the Ffestiniog district. In addition to correcting some inaccuracies on the Survey-Maps, and defining the exact position of beds hitherto doubtfully placed, they had brought forward conclusive evidence to show that the granite (so-called "syenite") of Tan-y-grisiau was intrusive in the surrounding rocks. This mass, in a paper in 1879, he had placed with the pre-Cambrian rocks, mainly on the strength of evidence supplied to him by the late Mr. Tawney; but in the map which he prepared for the excursion of the International Geological Congress in 1888, he (Dr. Hicks) corrected that error and indicated it as an intrusive mass as properly shown on the Survey-Maps. As the Cambrian grits in the neighbouring Harlech Mountains are largely made up of broken quartz and felspar, and of pebbles of granite, it seems probable that this intrusive granite mass at Tan-y-grisiau may after all be but a softened or fused portion of a pre-Cambrian floor (composed of granitic and gneissic rocks), which was intruded into the overlying rocks mainly as the result of pressure during subsequent earth-movements. The similarity between some of the fragments in the Harlech conglomerates and portions of this granitic mass is very striking.

Mr. Sherborn said that, with regard to Dr. Hicks's statement as to his omission of the pre-Cambrian area in the map printed in the Excursion Report of the last Geological Congress, he must, in justice to Mr. Jennings, remind the Society that the printed matter referred to was marked "Épreuve sujette à révision" and could in no way be quoted until properly published in the Report of that Congress.

The President remarked that the present paper formed another good illustration of the kind of patient detailed work that was required in extension and correction of the broad outlines traced by the Geological Survey. He spoke in warm terms of the Survey-Maps of North Wales, but admitted that they could now be much improved. Alluding to one or two parts of the paper about which there might be differences of opinion, he pointed out that in discussing the nature and amount of alteration in the ring of contact-metamorphism, we must bear in mind that, besides the capacity of the surrounding rocks for being metamorphosed, there were probably also initial differences in the capacity of the eruptive rocks to produce alteration.

Mr. Williams thanked the Fellows of the Society, on Mr. Jennings' and his own behalf, for the manner in which the paper had been received.

In reply to Prof. Hughes he said that the cleaved fragments of

slate were numerous in the agglomerate, and lay in all directions, a fact which indicates that they were cleaved prior to their inclusion in the agglomerate, and sharp contortions such as might be expected on Prof. Hughes's theory were altogether absent.

The Garth Grit could be traced except for short distances, when it is obscured by faults, all the way from Tyobry to Glanypwll, and on the Manod side its relation to the beds above and below is the same as that to the beds on the western side. At Nant-y-derbyniad slate-quarry, near Llyn Serw, the Grit lies immediately upon Upper-Lingula Flags containing *Olenus scarabæoides*, *O. spinulosus*, and *Orthis lenticularis*; and still farther east, at Llechwedd-deiliog, there are beds immediately overlying it containing *Æglina*, *Ogygia Selwynii*, and *Palæarca*, so that, as Sir A. Ramsay has said, the Tremadoc beds disappear altogether to the east. He had been unable to find any traces of graptolites below the Garth Grit, and he did not believe that there was in this district any other grit which could be mistaken for the Garth Grit.

# 23. *On the* Drifts *of* Flamborough Head. By G. W. Lamplugh, Esq., F.G.S. (Read March 25, 1891.)

[Plate XIII.]

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## I. Introduction.

The object of this paper is to describe the glacial deposits which overlie the Chalk on Flamborough Head, and to show their relation to those of the neighbouring areas north and south of the headland. Though a considerable amount of scattered information respecting these beds has already been published *, no systematic or detailed account of the drifts as a whole has yet been carried out.

The district is one of peculiar importance for students of the glacial phenomena of our East coast, since it is at this point that the connexion between the drift of the hills and that of the plains

* A good bibliographical list up to the year 1885 will be found in the Geological-Survey Memoir on Holderness (by Mr. Clement Reid), pp. 163–170.

must be traced, the coast-line here passing from the low ground of Holderness (an unsubmerged corner of the plain of the North Sea) to the elevated and broken region of the Wolds and Moorlands, and of the North of England generally. And that the nature of this connexion is by no means obvious has been shown in the former attempts to unravel it. The promontory affords almost unparalleled facilities for such an investigation, for with an area of less than sixteen square miles it possesses a precipitous coast-line over fifteen miles in length, presenting magnificent sections in various directions through the thickest part of the drifts; and has, besides, in the interior, three or four miles of railway-cuttings, and chalk pits in abundance. If the glacial history of an area thus laid open cannot be deciphered, there must indeed be slight hope for less favoured localities.

In classifying the Yorkshire Drifts twenty-four years ago, Messrs. Wood and Rome * recognized in the Boulder-clays of Holderness three divisions: the "Hessle Clay," the "Purple Clay," and the "Basement Clay"; and of these divisions they supposed that the first-named and the last died out before reaching the rising ground of the Chalk Wolds and Flamborough, and that the "Purple Clay" alone (with its associated gravels) extended over the headland and the country lying to the northward of it.

In a later paper, by Mr. S. V. Wood †, this supposed absence of the Basement Clay from the coast sections north of Holderness was strongly insisted upon; and this interpretation remained for many years prevalent, and was incorporated in most discussions of the Yorkshire Drifts ‡.

It was with a learner's faith in this view, and with a similar faith in the recurrence of "interglacial" periods, that I commenced the study of the Flamborough sections over twelve years ago. But with the gradual accumulation of opposing evidence my confidence was weakened, until at length I have been driven to contrary conclusions on both points §.

In the following pages are embodied the results of my investigation. After a short description of the physical features of the area, and of the general distribution of the drift, a detailed account of the sections will be given; the various deposits will be afterwards separately discussed; and in conclusion certain questions as to the origin and correlation of the beds will be touched upon.

The labours of previous observers will be referred to as the sections noted by them are described.

* 'On the Glacial and post-Glacial Structure of Lincolnshire and South-east Yorkshire,' Quart. Journ. Geol. Soc. vol. xxiv. (1868) p. 146.

† 'On the Relation of the Boulder-clay without Chalk, of the North of England, to the Great Chalky Boulder-clay of the South,' Quart. Journ. Geol. Soc. vol. xxvi. (1870) p. 90.

‡ *E. g.* Jas. Geikie's 'Great Ice Age,' 2nd ed. pp. 366 *et seqq.*

§ In Mr. S. V. Wood's latest paper 'The Newer Pliocene Period in England,' Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 685, he seemed himself to assign a more extended range to the Basement Clay, and to recognize this division on the coast north of Flamborough.

## II. Physical Features of the Area.

As usual, the character of the glaciation of this area has been largely determined by the shape of the ground.

Flamborough Head, which forms the abrupt termination of the Yorkshire Wolds, may be described as a blunted triangle of high land jutting out eastward for six miles into the North Sea. Its base-line from the sea at Bridlington Quay to the sea at Speeton is also about six miles in length (see fig. 1). It is edged on both sides by precipitous cliffs of chalk, capped with variable drift, those on the north ranging from 440 feet at Speeton to about 150 feet in the neighbourhood of Flamborough; but on the south they are not nearly so high, excepting in one instance (Beacon Hill, 180 feet) rarely exceeding 125 feet. The more easterly portion of the north side of the promontory is for two miles broken up into numerous little bays and inlets, frequently guarded by outstanding rock-pinnacles, and tunnelled by caves; but the cliffs of the remaining four miles form a magnificent, unbroken, unscalable wall nearly everywhere over 300 feet in height.

Looking south from the headland across the open Bridlington Bay we see the low land of Holderness, narrowing to a point at Bridlington owing to the approach of the Wolds to the sea, but widening rapidly southward into an uneven plain twenty miles or more in width. This ground is made up altogether of drifts and later deposits, and, as is well known, is rapidly diminishing as the sea works its way back to its ancient bounds at the Wold-foot *.

Looking north from the escarpment at Speeton, the eastern end of the broad Vale of Pickering (here only about four miles in width), which is scooped out of the soft Speeton and Kimeridge Clays, separates the high land of the Chalk Wolds from the higher land of the Oolitic moorlands. In the eastern portion of this hollow the drifts have accumulated to a great depth.

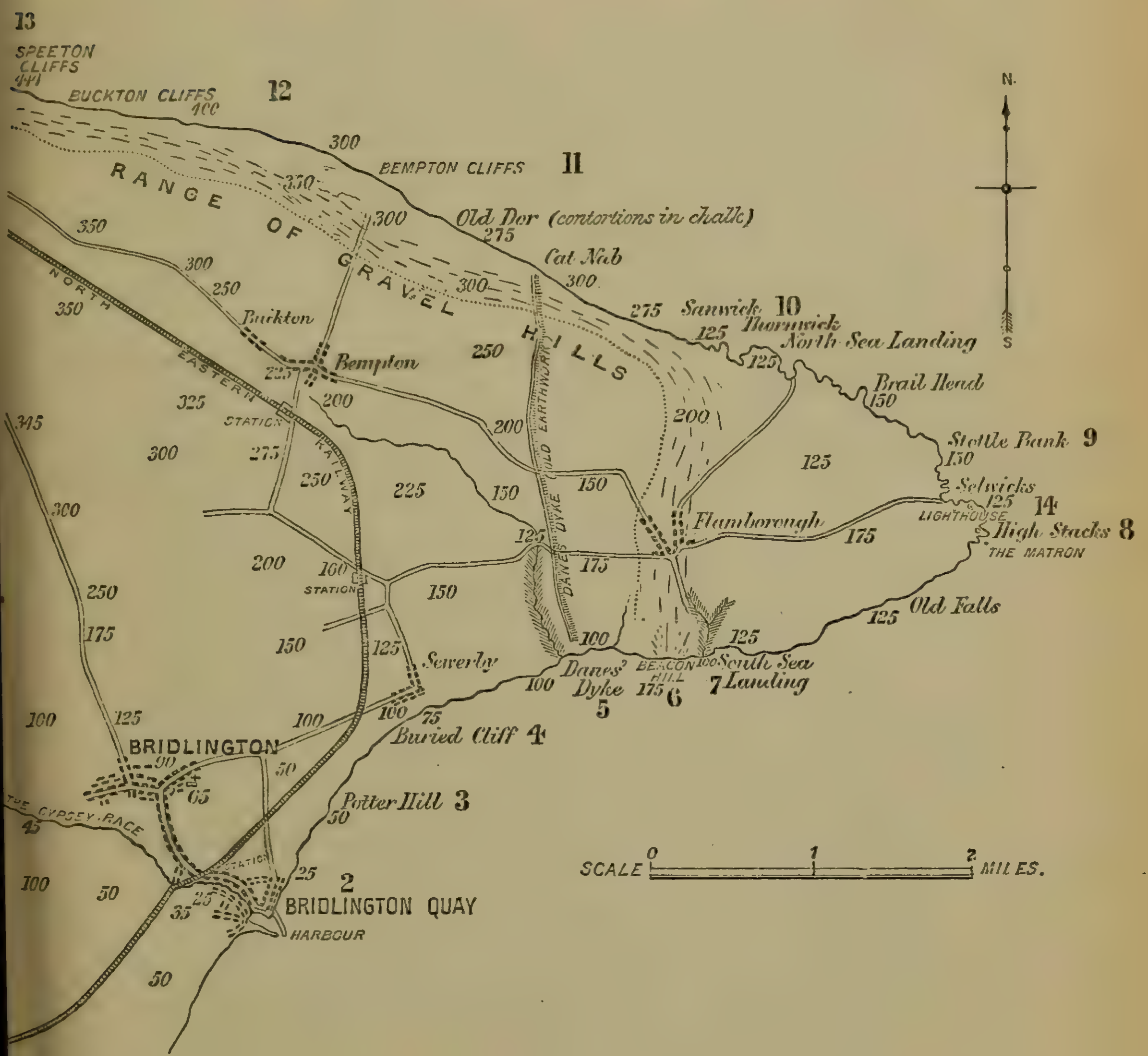
Inland, the steep escarpment, after leaving the coast at Speeton, trends W.N.W. for nearly four miles, to Hunmanby, where it is thrown northward for two miles by a fault; it afterwards swerves sharply west at Muston, and courses W. and W.S.W. for twelve or fourteen miles, rising everywhere in bold slopes above the Vale of Pickering.

From the edge of the cliff at Speeton and Buckton (whence we may look far westward along the smooth summits of the Eastern Wolds, rising to 500 feet in elevation) the ground falls away inland, leaving a broad depression which deepens eastward, and forms one branch of a shallow valley running roughly parallel to the north face of the promontory. This valley, which has its centre generally less than a mile distant from the cliff line, is the chief feature of the inland portion of the headland. The ground immediately to the west of it rises to not quite the height of the surface near the edge of the cliffs. It may be named the Bempton Valley, after a

* See Geol. Survey Mem. 'Holderness,' p. 6.

Fig. 1.—*Map of Flamborough Head.*

(From the Ordnance-Survey Map, Quarter-sheets 94 N.E. & 95 S.E.)




The small-type numbers indicate the elevation in feet; the large-type numbers refer to the figures of sections.

The position and course of the esker-like gravel-mounds is roughly indicated by the short strokes.

village which stands in it. East of Buckton, for about two miles, the cliff has not been cut back far enough to reach the summit of the ridge bounding the valley; but this is only a few hundred yards inland; and in approaching Flamborough, the valley-slopes are once more directly encroached upon.

The pre-Glacial course of the Bempton Valley seems to have been along the whole length of the headland, and its deep channel may still be seen buried beneath the drift at the easternmost point, near the Lighthouse, and elsewhere (see Pl. XIII. fig. 8). This channel was blocked during early Glacial times, and its drainage seems afterwards chiefly to have made its escape through the broad hollow in the Chalk at Danes' Dyke (Pl. XIII. fig. 5), a slender stream still, in wet seasons rising near Bempton, and finding the sea by this route. The relation of the drift deposits to the Bempton Valley is very curious, for while they are piled along the summit of its seaward edge, and also across its mouth, to a depth often exceeding 80 feet, on the slopes and at even lower elevations in the centre of the depression they dwindle to a thin covering rarely more than three or four feet in thickness.

On the south side of the headland the slope of the land is always towards the sea, except, as at Beacon Hill (Pl. XIII. fig. 6), where a drift-mound chances to stand at the edge of the cliff. This incline was evidently more strongly marked before the deposition of the Glacial beds, which are, in most cases, banked upon it and partially obliterate it.

At Bridlington Quay, in the south-west corner of the area, the largest valley of the Wolds reaches the sea. This, known as the valley of the Gypsey, or the Main Wold Valley, has a length of over twenty miles, and a drainage basin of about 86 square miles, commencing near Wharram, close to the western edge of the Wolds. The ground in the neighbourhood of Speeton, which lies beyond the head of the Bempton Valley (just west of the limits of the sketch-map, fig. 1), slopes westward towards this great valley, and any drainage flowing from the crest of the escarpment there would go three miles westward, and then southward and eastward for eight or nine miles till it reached the sea at Bridlington. It is probable that in Glacial times a large volume of water, issuing from the edge of the ice upon the escarpment, followed this course. At present the only water coming down the valley is an insignificant beck, the Gypsey Race, whose waters are, in dry seasons, entirely swallowed up by the thick and widespread sheets of ancient valley-gravel.

Only the lower reaches of the Main Wold Valley seem to have been occupied by ice during the Glacial period, at which time there was probably an accumulation of the drainage in its upper portion in the form of a temporary glacier-dammed lake.

Long after the disappearance of the ice, the mouth of the valley at Bridlington Quay seems still to have been blocked by Glacial deposits, so that its waters were diverted southwards across the Holderness plain, to follow a long and sluggish course till they reached the Humber. Part of its route at this period is still well

marked both by gravels and by the empty channel *, and with very little artificial aid the Gypsey Race might be sent once more to the Humber.

### III. General Distribution of the Drift.

Attention has frequently been directed to the fact that in East Yorkshire the Glacial deposits attain their greatest development at or near the coast-line.

This structure is strikingly exemplified on Flamborough Head, for, as already mentioned, on the south side the drifts are banked deeply against the inner slope of the Wolds, and on the north they are heaped up in thick mounds and ridges on the very summit of the escarpment, while inland they thin away so rapidly that the Chalk often carries nothing more than a scanty covering of clay within a few hundred yards of the edge of the cliff.

The kame-like mounds and ridges on the north side form a distinct chain (see fig. 1) which follows the highest part of the Chalk ridge south-eastward from Speeton to Sanwick, and there, where the cliff falls suddenly to 150 feet, leaves the coast and crosses direct to the opposite side of the headland, passing close by the village of Flamborough (as indicated on the map). Westward from Speeton also, this chain is extremely well-marked on the crest of the escarpment as far as the village of Reighton, a distance of about two miles; and it attains in this, the highest portion of its course, its maximum development, both in thickness and in sharpness of feature. Near Reighton it descends the escarpment and enters the Vale of Pickering, where, though its western edge is still well defined in the neighbourhood of Muston and Gristhorpe, its eastern boundary is less easy to trace, and merges into the general mass of the Glacial beds which block the mouth of the valley. Where this chain rests on the edge of the cliff, as at Speeton, Buckton, and Sanwick on the north side of the headland, and at Beacon Hill on the south, the structure of the mounds is frequently clearly revealed in the sections (see Pl. XIII. figs. 6, 10, and 12). In such cases the mounds are found to be largely composed of stratified material, often showing arched bedding. To the seaward of this chain, where it leaves the cliff, as at Flamborough and Speeton, a thick and complex mass of drift-gravels and Boulder-clays chokes the old valleys, while, on the opposite side, as a rule, only one thin Boulder-clay is present, and the valleys are open, or are filled with local gravels only.

The late Prof. H. Carvill Lewis, by whose untimely death in the midst of his labours so much was lost to glacial geology, examined these ridges with me early in 1887, and declared that they had marked the terminal limit of the great ice-sheet, and were the finest example of a true terminal moraine that he had yet seen in

* For a fuller discussion of this part of the subject, see my paper on 'Glacial Sections near Bridlington,' Part iii., in Proc. Yorks. Geol. & Polytechn. Soc. vol. viii. (1883) pp. 251 & 252.

England. I pointed out to him that the structure of the mounds, they being so largely composed of stratified material of fine texture, differed from any portion of the Great Terminal Moraine of America known to me; but he insisted that the position, outline, and mode of arrangement of the mounds were of prime importance, and that their composition was a secondary matter, depending on the shape and character of the terminal slope of the glacier and of the receiving surface, and the distance of the material from its original source; and added that similar local modifications were by no means unusual in the States *.

I shall have occasion to revert to these views of Prof. Carvill Lewis in a later portion of my paper.

## IV. Description of the Sections.

In attempting to describe over fifteen miles of ever-changing sections, it will of course be possible to record only a small portion of the details of the beds; but in some cases fuller descriptions have already been published in my former papers †, in the publications of the Geological Survey ‡, and in other works which are mentioned in the footnotes. Under such circumstances it must be remembered that some of the facts brought into prominence might

* These views were incorporated by Prof. Carvill Lewis in his papers read at the British-Association Meeting of 1887; see also Warren Upham, in Geol. Mag. (1889) p. 157; but as only short abstracts of these papers were published, I think no excuse is needed for now dwelling upon these valuable expressions of opinion.

† 'Freshwater Remains in the Boulder Clay at Bridlington,' Geol. Mag. (1879) p. 393 (with section near Sands Cottage); 'On the Divisions of the Glacial Beds in Filey Bay,' Proc. Yorks. Geol. & Polytechn. Soc. vol. vii. (1879) p. 167; 'On a Fault in the Chalk of Flambro' Head, with some notes on the Drift,' *op. cit.* vol. vii. (1880) p. 242; 'On a Shell-bed at the base of the Drift at Speeton,' Geol. Mag. (1881) p. 174; 'On the Bridlington and Dimlington Shell-beds,' *ibid.* (1881) p. 535 (with section opposite the Alexandra Hotel); 'Glacial Sections near Bridlington,' pt. i., Proc. Yorks. Geol. & Polytechn. Soc. vol. vii. (1881) p. 383 (with section north of the town); pt. ii. *ibid.* vol. viii. (1882) p. 27 (with section south of the town); pt. iii. *ibid.* (1883) p. 240 (with drainage-sections and geological map); pt. iv. *ibid.* vol. xi. (1889) p. 275 (with section opposite Beaconsfield Terrace); 'Thornwick Bay,' *ibid.* vol. viii. (1882) p. 103; 'On Shelly Patches in the Boulder-clay at Bridlington Quay,' Quart. Journ. Geol. Soc. vol. xl. (1884) p. 312 (with ground-plan, list of shells, and figures); 'On the Buried Cliff at Sewerby,' Proc. Yorks. Geol. & Polytechn. Soc. vol. ix. (1887) p. 381 (with sketch and section); 'Reports of Committee, &c., on an Ancient Sea-beach near Bridlington Quay (Buried Cliff),' Brit. Assoc. Report (1888), p. 328, and also *ibid.* (1890); 'On the larger Boulders of Flambro' Head,' pt. i., Proc. Yorks. Geol. & Polytechn. Soc. vol. ix. (1887) p. 340; pts. ii. & iii. vol. xi. (1889) p. 231; pt. iv. vol. xi. (1890) p. 397 (with petrological notes by Alfred Harker, M.A., F.G.S.); 'Cliff Section at Hilderthorpe,' Proc. Yorks. Geol. & Polytechn. Soc. vol. ix. (1887) p. 433; 'On a new Locality for the Arctic Fauna of the Basement Clay,' Geol. Mag. (1890) p. 61 (with sections at South Sea Landing); 'Notes sur la géologie de Flamborough Head,' Explications des Excursions: Internat. Geol. Congress, 1888 (with section between Sewerby and Bridlington Quay, &c.).

‡ Survey Memoirs: 'Holderness' (1885), by Clement Reid, F.G.S.; 'Bridlington Bay,' by J. R. Dakyns, M.A., and C. Fox-Strangways, F.G.S.; 'Oolitic and Cretaceous Rocks south of Scarborough,' by C. Fox-Strangways, F.G.S.

by another observer be considered of less importance than others which have been passed over.

The sections figured as illustrative of the beds are drawn to a true scale, though sometimes slightly foreshortened, to bring within their limits some feature of interest which might otherwise lie beyond them.

At the south-western corner of the area, the sections adjoin the better known sections of Holderness, and I take this for my starting point in describing the beds.

(a) *Bridlington Quay* (Pl. XIII. fig. 2).—Full descriptions, with large-scale sections (60 feet to 1 inch, with enlargements of 10 feet to 1 inch), having already been published of the cliffs in the immediate vicinity of Bridlington Quay *, a passing reference to them will suffice. These sections are now nearly all concealed by the structures raised to defend the coast from the encroachments of the sea. Their general character is illustrated in Pl. XIII. fig. 2. The dark shelly "Basement Clay" of Holderness (4 of fig. 2) is recognized between high- and low-water marks south of the Harbour, and rises into the cliff close to the town, probably moulded upon a chalk-ridge. Half a mile farther north it reaches a height of 15 feet above high-water mark (Beaconsfield Terrace), and a boring on the foreshore at this place proved its total thickness to be at least 35 feet; but northward it sinks rapidly, and goes below high-water mark off the Alexandra Hotel.

It is where the clay is highest in the cliff that the more important of the shelly patches which occur in it have been found †, these being irregular masses of sand and clay, as truly "boulders" as the similar mass of Lower-Lias shale observed by John Phillips ‡ on the adjoining foreshore.

South of the Harbour the Basement Clay is overlain by finely laminated gutta-percha clay of variable thickness, quite free from stones or other inclusions; but this bed disappears where the Boulder-clay rises above high-water mark, reappearing, however, when that bed sinks again to the shore on the north side of the town (4 *a* of fig. 3).

Above the laminated clay, or, where that bed is absent, directly upon the Basement Clay, we find dark brownish Boulder-clay, with intercalated gravels (3 *a*, 3 *b*, 3 *c* of fig. 2), evidently the same as the "Purple Clays" of the Holderness sections. This clay is generally divided into two parts, as in Holderness, either by the lenticular seams of sand and gravel (3 *b*) or by a well-marked stratified band (South Sands). It is generally possible to detect worn fragments of marine shells in the Purple Clay, though they are very much rarer and in worse preservation than in the Basement Clay. Similar fragments may also often be found in the associated gravels.

The uppermost portion of the Boulder-clay in fig. 2, though it is not very distinctly separable from the "Purple Clay," is, in every

* 'Glacial Sections near Bridlington,' pts. i., ii., iii., & iv. *op. cit.*

† For lists of shells and other details, see papers cited above.

‡ 'Geology of Yorkshire,' pt. i. 3rd ed. p. 85.

way, similar to that classed as a separate deposit by Messrs. Wood and Rome in the Holderness sections under the title of "Hessle Clay" *. Farther north every trace of a dividing line at this horizon disappears.

On either side of the ridge of Boulder-clay on which the Quay † stands, an extensive series of stratified beds fills the depression in the Boulder-clay surface. On the south side these consist chiefly of ripple-marked sands and warp ("the Hilderthorpe series" ‡); and on the north of well-bedded chalky gravels ("the Sewerby Gravels" §), the latter overspreading most of the sloping ground bordering on the sea between the Quay and Flamborough village (2 *b* of figs. 3, 4, and 5). These beds seem to be of Glacial age, and have been referred by Mr. S. V. Wood to the agency of waters issuing from the melting ice of the "Hessle-Clay" period ‖. I have myself tried to show ¶ that they have more probably been deposited by fresh water issuing from the great valley of the Wolds.

In the lowest ground on either side of the town freshwater marls a few feet in thickness, with layers of peat, make their appearance above the drifts; but as these should clearly be classed as post-Glacial, I shall not again refer to them. There is evidence, however, that the climate was still much colder than it now is when the deposition of these marls began **.

(b) *Potter Hill* (Pl. XIII. fig. 3).—In the section just described (fig. 2) all the leading features of the Holderness cliffs are more or less distinctly traceable; but in the mile-long interval between this place and the sudden appearance of the Chalk in the cliff at Sewerby, great changes supervene which completely alter the aspect of the sections. Unfortunately the cliff within this space is nearly always obscured by slips and talus, and it is only within the last two years that the excavations into the bone-yielding beds at Sewerby, and the erosion of the cliff and beach during a winter's storm, have presented a combination of circumstances favourable to the unravelling of the section. The chief features as I now read them are embodied in figs. 3 and 4 ††.

The Basement Clay does not die out, as had been supposed, against the rising slope of the Chalk, but after continuing for half a mile on the foreshore between tide-marks, rises again into the cliff

* Quart. Journ. Geol. Soc. vol. xxiv. (1868) p. 146.

† Local abbreviation for 'Bridlington Quay.'

‡ 'Glacial Sections,' pt. ii. *supra cit.*; also J. Phillips, 'Geol. of Yorks.' pt. i. 3rd ed. p. 82; and H. C. Sorby, West-Riding Geol. & Polytechn. Soc. vol. iii. (1852) p. 220.

§ J. R. Dakyns, 'Glacial Beds at Bridlington,' Proc. Yorks. Geol. & Polytechn. Soc. vol. vii. (1879) p. 124.

‖ 'The Newer Pliocene Period in England,' part ii., Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 716.

¶ 'Glacial Sections,' pt. iii. *supra cit.* p. 252.

** Dr. Nathorst 'Ueber neue Funde von fossilen Glacialpflanzen,' Engler's botan. Jahrbuch, (1881) p. 431, and Mr. Clement Reid's Holderness Memoir, p. 78.

†† See also 'Glacial Sections,' part iv. *supra cit.*, and section in 'Explications des Excursions,' Internat. Geol. Congress, (1888) p. 165.

east of Potter Hill, and mounts by a long slope to the top of the Chalk as shown in fig. 4.

The laminated clay (4 *a*, fig. 3) becomes associated with chalky gravel and sand, and seems finally to pass into stony Boulder-clay and to be absorbed into the Basement Clay, except its uppermost layers, which are prolonged as a thin seam of silty gravel (3 *b*) between the two Boulder-clays overlying the Chalk (Pl. XIII. fig. 4).

The behaviour of the Purple Clay is unexpected, and deserves especial attention as elucidating many perplexing differences between the low-level and high-level drifts. South of Potter Hill * there are two well-marked bands of Purple Clay, separated by chalky gravel from 2 to 6 feet thick; but when these reach the rising ground the lower band is shredded out among stratified loam, silt and sand, and disappears altogether, while the upper division is also partly absorbed among similar, though rather more gravelly, beds. The remaining portion of the upper division passes over the dome-shaped mass of stratified beds, which thus almost monopolize the section (Pl. XIII. fig. 3).

This hill is evidently a mound of the same character as those of the kame-like chain already described, but its true outline is partly masked by the Sewerby Gravels.

North of the hill the stratified beds seem, amid great confusion, to pass back into Boulder-clay, but this part of the section is still overgrown and obscure. Beyond this point, however, the Boulder-clay overlying the Basement Clay is in one mass (Pl. XIII. fig. 4) without divisions.

(c) *Sewerby.*—The two Boulder-clays above the Chalk at Sewerby represent, therefore, the lower, the Basement Clay of Holderness, and the upper, whatever remains of all the overlying divisions, though, as will presently appear, the correlation holds good only in a broad sense.

The Sewerby Gravels (2 *b*) in this part of the cliff, and indeed generally, contain a large proportion of flattish subangular fragments of chalk, usually measuring up to 2 or 3 inches in breadth, but in a few places ranging up to 8 or 10 inches. These "platy" fragments are such as might result from the shivering by frost of the hard Yorkshire Chalk, with a subsequent slight washing of the detritus. Taken in connexion with the presence elsewhere of similar chalky gravels (as at Danes' Dyke) at other horizons in the drift, and the scarcity of chalk in the Boulder-clays of the headland, they seem to indicate an exposed Chalk surface in the neighbourhood throughout Glacial times †.

In the cliff south of Sewerby, for the first time in the coast-sections, the base of the Glacial beds is brought above high-water mark. Here the Basement Clay is seen to rest upon a thick bed of compact chalky rubble (5, of fig. 4), the junction between them

* For this section, see J. R. Dakyns, 'Glacial Beds at Bridlington,' Proc. Yorks. Geol. & Polytechn. Soc. vol. vii. (1879) p. 123; or my paper on 'Glacial Sections,' part i. *supra cit.*

† 'Glacial Sections,' part ii. *supra cit.* p. 36.

being sometimes clearly defined and sometimes irregular and suggestive of passage (see Pl. XIII. fig. 4). This rubble is a curious hard cement-like mass of small subangular chalk-débris mixed with a little marly clay, and with, very rarely, a small erratic pebble. It shows obscure flowing lines of stratification, which are not, however, suggestive of deposition in water. A large limb-bone of *Bos* or *Bison* was recently found in it, probably derived from the underlying Blown-sand.

The thickness of this bed where it first appears at the cliff-foot was proved by a boring * to exceed 21 feet, but as it rises it thins rapidly, so that there is not more than 12 feet of it in the cliff when its base is first seen ; and before reaching the Chalk on the crest of the buried cliff it has dwindled to less than one foot, and indeed in one place disappears entirely. Its extension southward beneath the Basement Clay at some depth below sea-level was proved by its occurrence at a depth of 22 feet in a boring on the foreshore at Bridlington Quay.

(d) *The Buried Cliff* (Pl. XIII. fig. 4).—The solid Chalk appears suddenly in the cliff just opposite the village of Sewerby, fronting the drifts in an abrupt wall 30 or 40 feet high ; this has been formed by marine action prior to the deposition of any of the above-described Glacial beds, and afterwards buried and obliterated by the accumulation of materials banked against it (fig. 4). These materials differ from anything found elsewhere on the coast, and are altogether a most interesting series. They consist of the following members :—

(A) An old sea-beach of rounded pebbles, chiefly of chalk, which rests on a sea-cut platform of solid Chalk, and is piled up at the foot of the old cliff to a depth of four or five feet. The upper surface of this beach is not much above the present level of the highest tides.

(B) A rainwash of marly clay and fallen chalk, containing land shells and bones, which rests on the old beach close under the cliff, being there about five feet thick, but disappears at less than 7 yards from the cliff.

(C) A thick mass of fine wind-drifted yellow sand, with a few blocks of fallen chalk, which rests on the rainwash, or, where that is absent, on the old beach. This bed has a thickness in one place of over 25 feet, and reaches quite to the top of the old cliff (as shown in the section, fig. 4), where it is cut out by the chalky rubble and Basement Clay. The cliff-face behind this blown sand has been beautifully smoothed and rounded by the friction of the wind-driven particles, and has an aspect quite unlike that of the recent Chalk-cliff adjoining.

The great value of this series † is that all the beds are fossili-

* 'Report on Ancient Sea-beach, &c.' Brit. Assoc. Rep. (1888) p. 336.

† The general resemblance of this section to the buried cliffs of the South of England is very striking, especially in the arrangement of the beds, in the presence of 'landwash' over the beach, and of local rubble above the landwash. See A. Tylor, Quart. Journ. Geol. Soc. vol. xxv. (1869) p. 79, and Prestwich, *ibid.* vol. xxxi. (1875) p. 36.

ferous. Bones of mammals, fish, &c., along with a few badly-preserved sea-shells, occur in the old Beach; bones of mammals and birds, with some small snails, in the Rainwash; and similar remains in the Blown-sand (for list of species, see p. 411, and also papers quoted at p. 390). By the aid of grants from the Yorkshire Geological and Polytechnic Society, and from the British Association, the beds have been systematically quarried and a large series of the fossils collected.

It is quite evident from this section that the headland as a feature in the coast-line dates back to a period prior to the deposition of the Yorkshire drifts, and that an ancient range of sea-cliffs in approximately the same position as the present coast-line, but extending much farther westward and southward, was buried under Glacial and other débris, and is now being slowly disinterred and brought to its ancient condition, as the sea swallows up Holderness and comes to its own again. When we consider the time-interval and the great cycle of events which have passed since the stones of this old beach were rolled up by the sea, it is sufficiently remarkable that there should be so little difference in the sea-level that the waves to-day resume their ancient work, and rearrange the same pebbles into another beach under the same old cliff.

Where the old tidal platform of Chalk has not long been subjected to fresh erosion, we walk on the actual surface trodden thousands of years ago by the extinct animals (for I dare say these creatures came sometimes to the water-side) whose bones we have disinterred. The existence of this platform, which can be traced outward for quite 200 yards and seems to extend much farther, shows that the land must have been for some time stationary before the slight elevatory movement took place which brought about the accumulation of the Landwash and Blown-sand under the lee of the cliff.

The age of these beds will be discussed, and some further details given respecting them, in a later portion of the present paper (see p. 410).

(e) *Sewerby to Danes' Dyke.*—With the incoming of the Chalk the trend of the cliff-line changes from a north-east to an east-north-east course. For the next mile the sections show from 30 to 60 feet of chalk (Upper Chalk without flints) capped by about the same thickness of drift *. The uneven surface of the Chalk is much broken, and in some places slightly contorted, and between the base of the Boulder-clay and the solid rock there is generally a foot or more of chalk-rubble, usually much rougher in texture than that of the Sewerby section. This rubble thickens in the little hollows of the Chalk. For some distance the two Boulder-clays shown in fig. 4 may be readily traced by a well-marked difference in colour, and also by being often separated by a seam of silt, sand, or gravel; but the Basement Clay frequently shows a tendency to pass into or include stratified and contorted beds of sand and loam, and as we go east-

* Some details of these drifts will be found in J. R. Dakyns's 'Glacial Deposits north of Bridlington,' Proc. Yorks. Geol. & Polytechn. Soc. vol. vii. (1880) p. 246.

wards this peculiarity becomes so marked that it is often difficult to define the exact upward limit of the division, especially in places where the lower layers of the upper Boulder-clay are also stratified.

The capping gravels (Sewerby Gravels) of these sections are separable into two distinct and well-defined portions, the lower consisting almost entirely of dark drift-pebbles, while the upper part, in strong contrast, contains much white chalk. A similar arrangement prevails in many of the gravel-beds farther east.

The lower part of these gravels is often curiously interlocked with the upper part of the Boulder-clay *, and the evidence points to a simultaneous deposition of Boulder-clay and gravel.

(f) *Danes' Dyke* (Pl. XIII. fig. 5).—In this fashion, with continual minor changes of detail, the beds may be traced to within 300 yards of the Danes' Dyke ravine, where more striking variations occur. Stratified chalky gravels with some sand are developed both above and below the Basement Clay, and also, apparently, in the midst of the upper Boulder-clay; and these gradually thicken at the expense of the clays until at one place they usurp, for a short distance, the whole of the section above the Chalk. Thin bands of Boulder-clay soon reappear, however, and gradually thicken as they approach the ravine. The coast-line here crosses a wide hollow in the Chalk cut down to sea-level, which has been filled in with drifts, and since partly re-excavated (see Pl. XIII. fig. 5). The section at this place shows complex alternations of Boulder-clay and gravels whose arrangement will be best understood by reference to the figure †. Of the bands of Boulder-clay the two lowermost ($4^1$, $4^2$) die out against the Chalk-slope. The space between them is held by rough morainic gravel containing much chalk in large blocks, and seams of cross-bedded sand (4 *b*) which also disappear. The higher of these clays fades off in places into the overlying stratified deposits, and it contains many shell-fragments, among the species present being *Saxicava norvegica*, *Cardium grœnlandicum*, *Nucula Cobboldiæ*, *Tellina balthica*, &c. I have spent much time in exploring this section ‡, and consider that the beds up to this horizon represent the Basement Clay, while the persistent upper band of brown Boulder-clay (3) is all that remains of the upper Clay of Sewerby, this bed and the underlying sand and gravel (3 *b*) together taking the place of the Purple Clays of Bridlington and Holderness.

Above this clay lie the Sewerby Gravels (2 *b*), the lower part chalkless, and the upper layers composed chiefly of chalk-pebbles, as noticed farther west. A few feet of loamy stuff overlies these gravels at the cliff top (2 *c*), resembling a weathered Boulder-clay; and a little farther east (near Hartindale Gutter) a seam of Boulder-clay certainly appears in these gravels, their contemporaneity with

* See Dakyns, *op. cit.* (with sections illustrating this peculiarity).

† See also diagrams in J. Phillips's 'Geology of Yorkshire,' 3rd ed. pt. i. p. 91; and J. R. Dakyns, 'Glacial Deposits north of Bridlington,' *supra cit.* figs. 2, 3, 4, and 5.

‡ To examine these drift-sections above the chalk-cliffs with safety it is necessary to fix a light rope at the top, to give secure hand-hold.

the uppermost part of the Boulder-clay, and consequently their Glacial age, being thus fully established.

I believe that the reason for the predominance of gravels in this neighbourhood is that the waters of the Bempton valley have, as already suggested (p. 388), sought this outlet under the lee of the headland, when their original course eastward was blocked by the ice.

A noteworthy feature in this section is that the upper layers of the Chalk on the western slope of the valley are thrown into remarkable contortions, which fade out downwards (see Pl. XIII. fig. 5). More convincing instances of glacial folding will presently be described, but these contortions seem also to have been accentuated, if not actually initiated *, by ice-pressure; though it is curious that these disturbances should be found not only on the higher part of the slope, where the Boulder-clay and coarse gravels are in direct contact with the Chalk, but also in the valley-bottom, where there is 6 or 8 feet of fine chalky rubble (5), overlain by an almost equal thickness of well-bedded and apparently undisturbed silt and sand (5 *a*) between the lowest band of Boulder-clay and the Chalk. I have, however, recently seen in the fine chalk-rubble a large boulder of quartzite, 21 inches in diameter, proving the presence of ice, either during or prior to the formation of this bed †.

(g) *Hartindale Gutter.*—East of Danes' Dyke the section is less complicated; the gravel beds in the Basement Clay die out upon the slope and the clay-bands unite, so that we find again only two Boulder-clays with a stratified bed between them. The Chalk now rises higher, its thickness in the cliff ranging between 50 and 80 feet; and as there is for some distance no corresponding rise in the surface, the drifts lose what the Chalk gains. Landslips and thick vegetation render the sections very obscure for over a quarter of a mile, and in this space the Upper and Basement Clays seem sometimes to be merged into one mass.

At Hartindale Gutter, which carries the drainage of Flamborough, there is a clear section, not only in the cliff, but also in the ravine at right angles to it. Here it is seen how rapidly the drifts thin out inland, and how many of the difficulties of the sections may be due to this cause. In the face of the cliff only one Boulder-clay is seen, presumably the Basement Clay, overlain by chalkless, and chalky, gravels; but a few yards up the ravine an upper band of Boulder-clay appears between two of the gravel-beds, and seems to thicken inland, the section somewhat resembling that on the east side of High Stacks (Pl. XIII. fig. 8). This upper Boulder-clay also makes a fitful appearance in the gravels in the cliff, both east and west of the Gutter.

This section illustrates the difficulties which meet us in attempting a correlation of the clays and gravels of different localities, the

* There are some indications of a fault in the Chalk close by, which may be partly responsible for this disturbance of the beds.

† It has been supposed that the rubble was formed as a rainwash of the Chalk, Dakyns, *op. cit.* p. 248; see also p. 415 of this paper.

connexion between the beds being so intimate that it is scarcely possible to separate them.

(h) *Beacon Hill* (Pl. XIII. fig. 6).—Beyond Hartindale Gutter the cliff rises steadily, till in a quarter of a mile it has gained an additional 50 feet or more of altitude, attaining a total height of about 180 feet, afterwards sinking sharply towards the depression of South Sea Landing. The conspicuous mound-like feature thus formed, known as Beacon Hill, stands, as already mentioned, at the southern end of the chain of kame-like hillocks.

Its structure is admirably revealed in the cliff-section (see fig. 6); and the arrangement of the beds in it closely resembles that seen in many of the Holderness mounds, to which its likeness is indeed more striking than in the case of any of the mounds farther north *. We find from the cliff-section that the surface-feature is not due to any increase in the height of the Chalk, but that it is entirely caused by the exaggerated development of the stratified beds of the drift.

Above the Chalk there is Basement Clay (4), not much thicker than usual, with occasional fragments of marine shells. In its upper portion this clay exhibits, in places, signs of passage into the overlying stratified beds, so that no sharp line can be drawn between them. These stratified beds (3 *b*), which in the heart of the mound have a total thickness of over 80 feet, consist, in the lower portion, of tough laminated clay and warp, passing upwards into strongly cross-bedded and faulted sands with fine gravel, while in the upper part of the hill the gravels predominate. A few small shell-fragments, of the same species as those that occur in the Basement Clay, may be picked out of the gravel, but the fine sand and warp contain no fossils whatever. In the middle of the hill these stratified beds come quite to the surface, but on either flank they are overlapped by reddish Boulder-clay (3), which rises higher on the eastern slope than on the western.

This is essentially the structure of all these mounds, whether on Flamborough Head or in Holderness, in spite of great variation of detail—a lower dark Boulder-clay, an intermediate series of more or less stratified material, and an upper brown or red Boulder-clay often discontinuous over the crest. Often where a lenticular patch of sand or gravel is revealed in the cliff between two Boulder-clays without actually showing the mound-structure, close examination will demonstrate that the section does indeed cross the margin of a mound whose centre either lies inland or has been carried away by the sea.

In descending the eastern slope of Beacon Hill, the overlapping Boulder-clay thickens so rapidly that in less than 200 yards it has replaced or cut out the greater portion of the stratified beds, leaving only a gravel band a few feet in thickness; and before reaching the little bay of South Sea Landing even this has disappeared, the

* See also diagram in J. R. Dakyns's 'Glacial Deposits north of Bridlington,' *supra cit.* fig. 6; and Phillips, 'Geol. of Yorks.' 3rd ed. pt. i. p. 91.

two Boulder-clays seeming to merge, in an obscure section, into one inseparable mass (Pl. XIII. fig. 7).

(i) *South Sea Landing* (fig. 7).—The cliffs of the South Landing reveal another fine example of a drift-filled hollow in the Chalk. This differs, however, in outline from that of Danes' Dyke, the Chalk falling suddenly on the west side in a steep cliff, in outline not unlike the buried cliff at Sewerby. From the foot of this cliff a flat platform of Chalk extends for 60 or 70 yards, suggestive of marine rather than of fluvial erosion (see Pl. XIII. fig. 7). On the platform there rests a coarse rolled gravel (5 *b*), not unlike a beach gravel in appearance, but I have not been able to discover in it any evidence confirmatory of its marine origin—neither shell, nor bone, nor *Pholas*-bored pebble such as abound at Sewerby; while drift pebbles are present in large numbers, which alone would serve to distinguish it from the Sewerby beach. It seems, moreover, to pass into undoubtedly Glacial beds on the opposite side of the bay. Above this gravel there lies a thick mass of well-bedded sand, silt, and fine gravel (5 *a*), also quite unfossiliferous, which passes up into the Basement Clay. These stratified beds are certainly not the equivalents of the Sewerby Cliff-beds. They are analogous to the lowest beds at Danes' Dyke (Pl. XIII. fig. 5, 5 & 5 *a*), the deposits in both cases having apparently accumulated in these recesses during the earlier stages of the Glacial epoch, when the advancing ice had not yet enwrapped the whole of the coast-line.

The upper part of the section is occupied by a mass of Boulder-clay, which represents the combined Basement and Upper Clays (3 and 4).

On the east side of the little stream which is now re-excavating the hollow, the section is quite different from that just described. A great mass of rough chalk-rubble, with occasional drift-boulders, holds the base of the cliff, seeming in one place to have a thickness of over 40 feet. Its true thickness, however, may not be so great, since it is probably banked against a concealed cliff of Chalk. It shows bold steeply-sloping planes of stratification sweeping down towards the valley. Towards the centre of the hollow this rubble becomes curiously contorted, and is intermingled with the overlying Boulder-clay in such a fashion as to suggest contemporaneous formation. I am inclined to regard this bed as the result of the combined action of frost and flood upon an adjacent exposed surface of Chalk when the drainage channels were blocked at their outlet. Where the Chalk reappears in the cliff this rubble thins rapidly, and finer stratified beds make their appearance above it.

I have recently described and figured * this part of the section in recording the discovery of a shred of fossiliferous sand in the Basement Clay, similar to the shelly patches of Bridlington and Dimlington, and I need not therefore treat of it here at length.

* Geol. Mag. (1890) p. 61. These sections have also attracted the attention of J. Phillips ('Geol. of Yorks.' 3rd ed. pt. i. p. 91); T. Mellard Reade, 'A Traverse of the Yorkshire Drifts,' Proc. Liverpool Geol. Soc. (1882–83) p. 11, with section; Wood and Rome, Quart. Journ. Geol. Soc. vol. xxiv. (1868) p. 180; and J. R. Dakyns (*supra cit.* p. 249).

The shelly sand occurs as a twisted seam, about 24 feet long, but never exceeding four inches in thickness, in a thin band of Boulder-clay which dies out rapidly between stratified beds. It has yielded about 20 species of mollusca; while in the stratified beds above and below the strip of Boulder-clay there is no contemporaneous fauna. Its position is about 60 feet above sea-level, this being the only instance in which a fossiliferous patch has been found more than two or three feet above high-water mark, or in which it has been possible to examine the underlying section. It fully confirms my previously expressed views as to the transported character of the shell-bearing patches, and also satisfactorily completes the identification of the lower Boulder-clay of Flamborough Head with the Basement Clay of Holderness.

(k) *South Sea Landing to High Stacks.*—Beyond the last-mentioned section for upwards of a mile there is nothing to call for special comment. The cliff, generally about 125 feet in height, is capped with 30 to 60 feet of drift, which is usually separable into two Boulder-clays about equal in thickness; but in a few places the lower division disappears into stratified beds, and only the Upper Clay persists, over sands or chalky gravels. In the neighbourhood of Old Falls (where a very precipitous path leads to the beach) the cliff-line intersects two or three small but sharply-defined mounds, and in each case, as in Beacon Hill, it is to a rapid thickening of the intermediate gravels under the Upper Clay that the surface-feature is due. In one of these instances this clay distinctly passes into rough morainic drift-gravel.

Beyond Old Falls the Chalk surface rises gradually, till there is in one place only about 12 feet of drift above it, consisting chiefly of gravelly red Boulder-clay; but whether this clay represents the upper or lower division, or both, it has not been found possible to decide, though the evidence favours the first-mentioned supposition.

In the neighbourhood of Cattlemere Hole, within half a mile of the extremity of the headland, the solid rock sinks rapidly again, and the drifts proportionately thicken till they once more attain a depth of 40 or 50 feet. Here the section shows many points of resemblance to that west of Danes' Dyke, chalky gravels, with sand and laminated silt, being developed at the expense of the Boulder-clays, till they monopolize for a short space the whole section, save that a thin band of Basement Clay, so chalky as to be scarcely distinguishable from the underlying chalk-rubble, persists at the base.

(l) *High Stacks* (Pl. XIII. fig. 8).—At High Stacks the easternmost point of the headland is reached, and the cliff-line swings round to the northward. Here the section intersects another hidden valley in the Chalk, a broad, shallow hollow, with a steep but narrow ravine in the centre. This seems to be the prolongation of the Bempton valley, and is evidently the result of stream erosion. The approach of the little ravine to the cliff-line has caused a curious feature. In two places between High Stacks and Selwicks the sea, which here assails the cliff far more violently than on the sheltered southern shore of the promontory, has driven caves through the firm flinty chalk of the outer

slopes of the valley until it has reached the looser drifts of the buried ravine, and these, yielding readily to erosion, have been withdrawn through the cave, so that deep pit-like *creux* or "blow-holes" have opened upwards into the ground near the cliff-edge, revealing excellent sections of the drift.

In the first of these (see Pl. XIII. fig. 8) * the dark Basement Clay (4), resting on rough chalk rubble (5), attains a thickness of over 25 feet and contains many shell-fragments. Its upper surface shows signs of erosion, and is overlain by 30 feet of gravel. The upper half of this gravel is full of chalk, very rough and morainic in texture, with numerous subangular, far-travelled, erratic blocks of large size ($3\,b^1$); while the lower half is of much finer material, either without chalk or with the rarest sprinkling of it ($3\,b^3$). The parting between these beds is conspicuously distinct, the upper seeming to cut down into the lower. On the north side of the *creux* a band of brown Boulder-clay, thinning out southward ($3\,b^2$), comes in between these gravels, and the same band may be traced in another section about 300 yards farther north.

The beach in this neighbourhood is thickly strewn with erratic blocks, some of them of large size, there being fully four thousand within 350 yards of the solitary chalk pinnacle known as The Matron. These have evidently been derived chiefly from the rougher portion of the gravel ($3\,b^1$) †.

The gravels are overlain by the earthy red Upper Boulder-clay (3), now the most constant factor of the sections, which reaches to the top of the cliff.

This *creux* is not shown on the six-inch Ordnance map, and seems to have broken through since the map was made; but the next, about a quarter of a mile farther north, is marked thereon as "Pigeon Hole."

(m) *Pigeon Hole.*—In Pigeon Hole thick sands underlie the Basement Clay as at South Sea Landing. These are evidently confined to the buried ravine, as they are not seen in the cliff-section above the outer mouth of the cave. A large boulder was for some time visible in these sands in an inaccessible part of the pit-walls.

The Basement Clay itself here splits up into layers of diverse composition, the lowest consisting chiefly of reconstructed chalk, the next of a *remanié* mass of Speeton Clay (Neocomian and Kimeridge), still containing many of the characteristic fossils ‡ of that deposit, while the upper layers alone are of the normal type of this Boulder-clay, containing, however, shell-fragments in greater abundance than usual. Gravel-streaks in some places intervene between these zones. Rough chalkless gravel overlies the Basement Clay, and above it the Upper Clay caps the cliff.

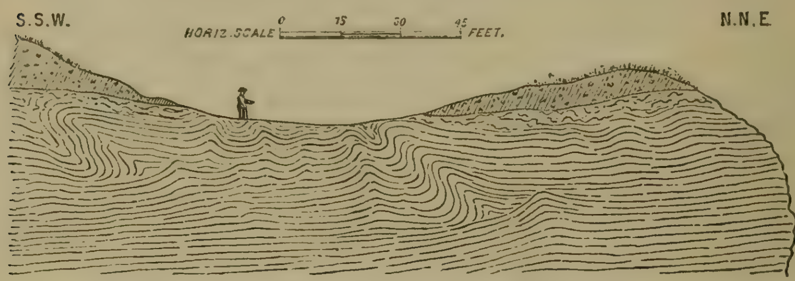
* See also J. R. Dakyns, Proc. Yorks. Geol. & Polytechn. Soc. vol. vii. (1879) p. 126, figs. iv. & v., and *ibid.* p. 250.

† See also 'The Larger Boulders of Flamborough Head,' pt. iv. in Proc. Yorks. Geol. & Polytechn. Soc. vol. xi. (1890) p. 397.

‡ These fossils show that the clay has been shaved off from the outcrop of the series, as nearly every zone between the Kimeridge shale and the Red Chalk, both inclusive, is represented.

(n) *Selwicks*.—In the bay called Selwicks *, just under the Lighthouse, the buried valley-side is quite cut through, but the section is slipped and obscure. Transported Neocomians seem to make up the greater part of the Basement Clay, and this peculiarity continues for over a quarter of a mile farther north.

Fig. 14.—*Section at the top of the cliff at Common Hole, Selwicks, showing surface-contortion in the Chalk.*




The wavy lines represent the Chalk-with-flints: top layers broken into rubble. Above is seen the dark 'Basement' Boulder-clay.

The uppermost layers of the Chalk on either side of the bay show very fine examples of surface-contortions due to glacial action. These are best seen on the north side near "The Limekiln," and on the south side in the outstanding ridge at "Common Hole" (shown in fig. 14) and above the mouth of "Kirk Hole." In all these cases the top beds of the Chalk are thrown into sharp folds, and the crest of the fold is generally broken and shaved off so as to pass imperceptibly into the overlying rough chalk-rubble or into Boulder-clay †. The force seems in every instance to have pressed forward from north to south ‡.

(o) *Stottle Bank* (Pl. XIII. fig. 9) *to North Sea Landing*.—Beyond Selwicks the buried valley passes obliquely across the headland, and the Chalk rises higher, so that at Stottle Bank, 500 yards north of Selwicks, the cliff shows less than 20 feet of drift, overlying 130 feet of Chalk (see Pl. XIII. fig. 9). As the drift thins the lower bands of the Basement Clay ($4^3$, $4^2$) die out successively upon the slope until only the shelly upper portion remains ($4^1$). This is overlain by gravels, and the gravels by reddish Upper Clay.

Beyond Stottle Bank the indented coast trends north-west, and for the next mile, in spite of considerable irregularity in the top of

* Wrongly written 'Silex Bay' on the Ordnance maps; fisherfolk do not usually add 'Bay' to 'Wick' or 'Wyke.'

† These sections are strongly confirmatory of the views put forward by Mr. Clement Reid to explain the folding of the Chalk and transportation of the Chalk boulders in the Norfolk Glacial sections. See Geol. Survey Mem. 'Cromer,' pp. 115–116.

‡ If any doubt remain as to the glacial origin of these disturbances of the rock-surface, the occurrence of a beautifully scratched and polished surface of Coralline Oolite, which I found last summer under the Basement Clay near Filey Brigg, 10 miles farther north, will serve to dispel it. The scratches pointed N. 20° E.

the Chalk, the surface remains plateau-like and regular, the drifts levelling up the inequalities. This portion of the headland lies definitely within the chain of gravel-mounds, and when one stands on these mounds and looks seaward it is remarkable how sharply defined is the difference between this smooth space and the uneven contours of the gravel-range bounding it. The same feature is noticeable under similar circumstances near Bempton.

Until we reach North Sea Landing the drift consists chiefly of Boulder-clay, sometimes in two, sometimes in three divisions, the lowest usually containing many black flints and also many shell-fragments. These flints are quite different in colour and shape from those of the underlying Chalk.

At North Sea Landing the Chalk sinks to within a few feet of high water, and the drifts thicken to nearly 100 feet, the lower portion consisting very largely of well-stratified sandy and silty beds which rest on thick chalk-rubble. As in other sections, these silts seem to pass into, or form part of, the Basement Clay, but there is considerable contortion and confusion, especially on the west side of the bay, where thick chalkless gravels make their appearance in the lower part of the drifts. The Upper Clay is continuous at the cliff-top, and is unaffected by the changes in the beds below.

(p) *The Thornwicks.*—Going westward, the Chalk rises to 70 or 80 feet in the flat-topped peninsula of High Holm, but sinks again to near high-water mark in the two inlets known as Great and Little Thornwick, where the buried valley-walls are broken through for the last time. The sections here are analogous to that of North Sea Landing, except that a very coarse morainic gravel without much chalk comes between the chalk-rubble and the Basement Clay in Little Thornwick. Stratified beds also again encroach upon the Basement Clay, consisting, in this case, chiefly of clean sand and fine gravel, with many shell-fragments. This gravel has yielded in Little Thornwick a single battered, but nearly perfect, specimen of *Trophon antiquum*, var. *contrarium*; but I do not regard it as of marine origin. I have found in the Basement Clay itself, just east of North Sea Landing, a perfect specimen of *Tellina balthica*, with valves united, and yet undoubtedly transported *.

(q) *Sanwick* (Pl. XIII. fig. 10) †.—Beyond Little Thornwick the old valley finally leaves the coast and the cliff-line becomes more regular. The ground now rises steadily, so that in less than a mile an elevation of over 300 feet is reached, the slope being most pronounced at its commencement near Sanwick. Near this place the cliff again reaches the skirt of the gravel-mounds and opens some partial sections in them. One of these is shown in Pl. XIII. fig. 10, wherein an intermediate Boulder-clay ($3\,b^2$), presumably equivalent to the Purple Clay of Holderness, is seen to be replaced by the gravels with arched bedding ($3\,b$) which form the heart of the mound. Traces of *remanié* Speeton Clay again appear in the Basement Clay.

Northward the gravel-mounds hang near the edge of the cliff as

* For a similar example at Bridlington, see Geol. Mag. (1881) p. 540.

† The fishermen say 'Sanwick,' not 'Sarnwicks,' as on the Ordnance map.

far as Cat Nab, with the effect of causing the thickness of the drift to oscillate between 60 or 80 feet and 10 or 15 feet.

(r) *Bempton* (Pl. XIII. fig. 11) *and Buckton* (Pl. XIII. fig. 12).—Beyond the northern end of the great prehistoric rampart of Danes' Dyke the mounds pass for a space inland (see Map, p. 387), hugging the crest of the Bempton Valley, and the drifts dwindle to a band of weathered Boulder-clay, in one place not more than two feet thick, resting on broken chalk or chalky gravel. In the overgrown state of the sections in this vicinity it is difficult to decide the exact relation of this clay, but there is every probability that it represents the Upper Clay, and that the Basement Clay has tapered off into gravelly material and crushed chalk. It must be borne in mind, as a point of great importance in considering the origin of the beds, that the thinning out of the deposits at this place is not directly dependent upon either the elevation or the slope of the ground, since the drift lies thinnest at Bempton, where the cliff is not more than 275 feet high, while at Buckton and Speeton, farther west, where the Chalk rises to between 350 and 400 feet, the Glacial beds have a thickness of from 35 to 60 feet, and both Upper and Lower Boulder-clays are certainly present.

This thin covering of red Boulder-clay with a pebbly base continues for over a mile. In one or two places, however, the drift thickens to 30 or 40 feet in depressions of the Chalk, and is again divisible into an Upper and a Lower bed (see Pl. XIII. fig. 11). At Buckton, where the gravel-mounds once more touch the coast, there are one or two clear sections showing admirably the kame-like arrangement of the Intermediate Series (see Pl. XIII. fig. 12) and the passage of earthy Boulder-clay through clayey gravel into clean-washed stratified beds. This structure would, I believe, be found in nearly every hillock if the section were cut in the proper direction for displaying it.

The highest point of the cliffs is reached at Raincliff, in Speeton parish, the altitude here being 440 feet*, of which over 50 feet is drift, chiefly gravel. Even at this elevation I have found a few fragments of marine shells (*Tellina balthica*, &c.) in the intermediate gravels, in which a few black flints also occur. The stratified beds frequently reach quite to the surface, as at Beacon Hill. The drift-mounds slope steeply inland, and thin out so rapidly in that direction that in some chalk-pits a little over half a mile from the edge of the cliff, and fully 100 feet lower in level, two or three feet of weathered Boulder-clay is all that remains of the Glacial series.

At Nanny Goat House, where one may descend, passing a small crevice or cave, to the beach by a dangerous path, a curious breccia coats the face of the vertical chalk-cliff for 70 feet or more below the base of the drift. This is composed of drift-boulders and pebbles mixed

* At Speeton Beacon, a mile farther west, the Chalk escarpment being here half a mile inland, the six-inch Ordnance map records 454 feet; but west of this there is a considerable decrease in the altitude of the crest.

with lumps of chalk and some sand, the whole cemented into a very hard mass by the percolation of water charged with lime. The breccia seems to have accumulated in an open joint-fissure of the Chalk, but it is not easy to decide whether the opening of the fissure took place in Glacial times; whether it is of post-Glacial date and has been afterwards filled in with falling drift from above, as certain other open joints in the neighbourhood have recently been; or whether it is simply due to a slip of drift having rested against the cliff-face. But as it is evident that a line of sea-cliffs did exist in this locality prior to the encroachment of the ice-sheet, and as the structure of the escarpment, which is based on clay, must always have favoured the formation of such fissures near its edge, there is nothing improbable in the first supposition. Somewhat similar breccias are of frequent occurrence on the headland (Danes' Dyke, South Sea Landing, Little Thornwick, &c.), but are usually horizontal, and have been formed from gravels lying between the Chalk and the Boulder-clay.

(s) *Speeton* (Pl. XIII. fig. 13).—Where the Lower-Cretaceous Clays emerge the coast-line abandons the Chalk escarpment and turns northward, thus determining the headland. The surface falls by a steep slope from over 400 to under 200 feet, and on this slope there is evidently very little drift, though the cliff-sections are unfortunately very obscure. In these sections, and also in the chalk-pits which have been driven into the face of the escarpment between Speeton and Reighton, we find only a slight depth of red gravelly clay above the Chalk, the slope having probably been too steep for much drift to lodge.

Some of the great slips of chalk which characterize the vicinity seem to have reached their present position before, or during, Glacial times, and are sometimes overlapped by the Glacial deposits and sometimes confusedly mixed with them.

Towards the foot of the slope the drifts thicken rapidly, comprising, at the base a rubble of fine subangular fragments of chalk with seams of sand, overlain by dark Basement Boulder-clay with irregular stratified beds, and this again by gravel and brown Boulder-clay. The deposits are therefore quite analogous to those on the escarpment, and also to those on the other side of the headland; and it is remarkable how slightly the character of the drifts is affected by this great and sudden change of level. Had there been, as has been supposed, a long mild interval between the formation of the different Boulder-clays, the older deposits would scarcely have withstood erosion and remained on the crest of this steep escarpment.

In the deep ravine of Speeton Gap, the drifts pass suddenly off the Chalk, on the northern side resting on the Speeton Clay, without any marked alteration of character. Some masses of Red Chalk which occur in the base of the deposits in Black Cliff seem to be included in the Basement Clay, but whether they are transported masses or merely pre-Glacial slips I have not been able to decide. Near the same place soft sands are found below the chalky rubble,

which are not at first fossiliferous; but 450 yards farther north, on the ridge between Middle Cliff and New Closes Cliff, where, after an interval of confusion and overgrowth, there is again a clear section, we find in the same position silt and sand sixteen feet thick, containing numerous shells. The shells, which are chiefly bivalves, are undoubtedly indigenous fossils, and prove the bed to have had a marine, or, more correctly speaking, an estuarine origin (see Pl. XIII. fig. 13)*.

The base of this shell-bed is not well-exposed; but the thin seam of gravel ($A^1$) which intervenes between it and the Secondary clays appears to be made up of fragments of *Belemnites* and other fossils washed out of the Neocomian, with chalk pebbles and other local detritus. I have, however, recently obtained a subangular weathered fragment of basalt, 3 inches in diameter, from the exposed face of the sands (A), and though the circumstances were not absolutely convincing because of the presence of much slipped Boulder-clay, they were strongly in favour of the erratic pebble having been actually embedded in the shell-bed.

The very limited fauna of this bed (see p. 412) indicates slightly estuarine conditions, such as might obtain when the drainage of the Vale of Pickering flowed eastwards to the sea, as it probably did before the deposition of the drifts. It also indicates that the bed was accumulated either between tide-marks or in very shallow water. There being nothing contradictory, so far as they go, in the faunas, the character of this bed and its stratigraphical position would amply justify its correlation with the Buried-Cliff beds of Sewerby, were it not for the considerable discrepancy in their levels, for while the Sewerby beach is very little above the present high-water mark, the top of the Speeton sands is fully 90 feet above the beach †. Thus a difference of sea-level of at least 80 feet is indicated, and if we consider the beds to be actually contemporaneous, we must suppose a tilt of the land to that extent within the six miles intervening between the two localities. But, for my own part, I should be very unwilling to admit so great a local displacement, since all my studies of the glacial phenomena of the district have tended to show that the *relative* levels of the surrounding region have not greatly altered since pre-Glacial times, and that whatever movements of elevation or depression there may have been have affected the whole area equally. Consequently, in spite of the difficulty in explaining the preservation of this incoherent deposit under conditions of elevation, I think that the Speeton sand, being the higher, is probably slightly older than the Buried Cliff-beds, since the Landwash above the Beach at Sewerby indicates that the movement of the

* See descriptions and discussions of this bed in Geol. Mag. (1881) p. 174; also J. Phillips, 'Geol. of Yorkshire,' 3rd ed. pt. i. p. 101, and Mr. C. Reid's 'Holderness' Memoir, p. 69.

† John Phillips describes them (*loc. cit.*) as being '105 feet from the shore;' but the figure given above was that arrived at by the late Prof. Carvill Lewis, who measured the altitude of the bed for me by means of the large aneroid which he carried.

period was one of elevation *. This point, however, may be reserved for further discussion and for the accumulation of fresh evidence.

Thin chalky gravel (5) covers the shell-bed; this, in turn, is overlain by 10 feet of dark Basement Clay (4) †; and this by sand and gravel (the Intermediate Series, 3 *b*) 5 feet, thickening rapidly northward; while at the top there is about 30 feet of brown or reddish Boulder-clay (3).

North of this section the cliff is a mass of slips, among which it is just possible to trace the shell-bed down the pre-Glacial denudation-slope of the Secondaries to beach-level under Gill Cliff, where it may sometimes be seen under the drift when the foot of the cliff is washed bare of shingle. Still farther north I have detected traces of it between tide-marks off Reighton ‡ (one mile); and a similar deposit seems to have been passed through in a recent well-boring close to Filey Station, four miles distant.

(t) *Filey Bay, &c.*—The sections north of Speeton lie beyond the limits of my area, but a few notes on them will be requisite for use in the concluding discussion.

Between Speeton and Filey the cliffs, from 100 to 150 feet in height, cross the drift-choked entrance to the Vale of Pickering and are composed entirely of Glacial deposits. The arrangement of the beds bears much resemblance to that in Southern Holderness §. Three, or even four, belts of Boulder-clay are sometimes traceable, differing in colour and other respects, and separated by irregular seams of sand and gravel. The lowest of these possesses all the characteristics of the Basement Clay of Flamborough. Near Mile Haven it includes several huge transported masses of Lower Lias, with the original bedding and fossils still preserved ||, and similar masses of Upper Lias also occur in the vicinity ¶. The uppermost clay resembles in every respect the Upper Clay of Flamborough and of the Holderness sections. Between the upper and lower clays we find in some places Boulder-clay comparable to the Purple Clay of Holderness, while in others only stratified beds of sand or rough morainic gravel occur, often exhibiting arched bedding.

These Filey-Bay sections may be taken as types for all the drift-

* I am sometimes inclined to think that the elevation of the Speeton bed may be a local phenomenon due to the upward bulging of the plastic Lower-Cretaceous clays under the weight of the Chalk escarpment; I have not, however, been able to collect any satisfactory evidence for such a movement to anything like the extent indicated.

† In my former description of the section (*supra cit.*) I supposed this to be 'Lower Purple' Boulder-clay, not being then aware of the northward extension of the Basement Clay.

‡ See 'Glacial Beds in Filey Bay,' Proc. Yorks. Geol. & Polytechn. Soc. vol. vii. (1879) p. 167.

§ See comparative sections in the above-quoted paper.

|| These masses have sometimes been mistaken for beds in place. See Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 580 (footnote).

¶ Leckenby, 23rd Rep. Scarborough Phil. Soc. (1855) p. 49. I have not yet seen these Upper-Lias masses, which are only occasionally exposed on the foreshore, but have recently examined a collection of fossils obtained from them. The Lower-Lias boulders are always visible in the cliff.

filled hollows of the coast to the northward. At Cayton, Scarborough, Robin Hood's Bay, Whitby, &c., though the details vary, the general arrangement is essentially the same.

(u) *Inland Sections of Flamborough Head.*—The inland sections scarcely need further description than has already been given. Usually nothing is revealed in them except a few inches, or, at the most, a few feet of weathered Boulder-clay resting on shaken Chalk, and even this is absent from the higher ground at the western edge of the area included in the Map (fig. 1, p. 387).

In one or two instances, however, local deposits of chalky gravels lead to some modification of the section, these apparently replacing the clay. The best example is in the deep railway-cutting north of Flamborough Station, which obliquely crosses a partially drift-filled hollow of the Chalk draining down to the Bempton valley, showing thick sand and chalky gravel with a few drift-pebbles banked against steep valley-walls of chalk. These beds are probably of freshwater origin; but I am not aware that they have yielded fossils of any kind. There are also one or two pits opened into the Sewerby Gravels in the neighbourhood of Marton.

The Late Glacial and Recent deposits at the mouth of the Main Wold Valley were excellently revealed in the Bridlington drainage-sections; but these have been discussed in another paper *.

## V. Boulders.

The shores of the headland are strewn with boulders derived from the wasting cliffs, generally thinly scattered, but sometimes in great numbers, especially, as already mentioned, towards the extremity of the promontory. There are at least 7000 boulders exceeding one foot in diameter on the beach between South Sea Landing and High Stacks. I have recently compiled several catalogues of the larger boulders lying within a given area, not only on Flamborough Head, but also, for the sake of comparison, at various other parts of the Yorkshire coast both north and south of Flamborough, and have been so fortunate as to obtain the assistance of Mr. Alfred Harker, M.A., F.G.S., in the petrological examination of the more interesting specimens †.

My lists have been condensed in the following table ‡:—

* 'Glacial Sections near Bridlington: Part iii. The Drainage Sections,' *supra cit.*

† 'On the Larger Boulders of Flamborough Head,' part i., Proc. Yorks. Geol. & Polytechn. Soc. vol. ix. (1887) p. 340; parts ii. & iii. vol. xi. (1889) p. 231; part iv. vol. xi. (1890) p. 397; also Reports of Brit. Assoc. (Leeds, 1890) p. 375.

‡ See Reports of Brit. Assoc. (Leeds, 1890), p. 375, and part iv. of paper above quoted, for further details.

| Boulders over 1 foot in diameter. Origin. | SOUTH HOLDERNESS, near Withernsea. 500 boulders on the beach. | NORTH HOLDERNESS, near Hornsea. 100 boulders in the cliff. | FLAMBOROUGH HEAD, south side. 1100 boulders, chiefly on the beach. | FILEY, near the Brigg. 100 boulders in the cliff. | CAYTON BAY, south side. 100 boulders in the cliff. | ROBIN HOOD'S BAY. 100 boulders in the cliff. | WHITBY, north of Upgang. 200 boulders in the cliff. |
|---|---|---|---|---|---|---|---|
| | per cent. | per cent. | per cent. | per cent. | per cent. | per cent. | per cent. |
| Carboniferous Limestone (including also a few other Palæozoic Sedimentary Rocks)......... | 22·8 | 17·0 | 23·3 | 13·0 | 14·0 | 13·0 | 30·0 |
| Sandstones, Grit, Conglomerate, &c. (probably all, or nearly all, from Carboniferous or other Palæozoic Rocks) ...... | 14·4 | 45·0 | 26·8 | 15·0 | 25·0 | 28·0 | 18·0 |
| Mesozoic Rocks (Jurassic Limestones and Sandstones, Chalk, &c.) ... | 22·1 | 22·0 | 1·0 | 51·0 | 40·0 | 48·0 | 35·5 |
| Basaltic and other Eruptive Rocks ............... | 37·3 | 14·0 | 43·2 | 19·0 | 18·0 | 7·0 | 15·5 |
| Granite, Schist, Gneiss, &c. ........................ | 3·4 | 2·0 | 5·7 | 2·0 | 3·0 | 4·0 | 1·0 |
| Total ............... | 100·0 | 100·0 | 100·0 | 100·0 | 100·0 | 100·0 | 100·0 |

As the boulders have, of course, been derived from various horizons, the above table indicates only the relative proportion of the different rocks contained in the whole mass of the drift without any discrimination of level. I believe that the rocks from the most distant localities, such as the granites (other than Shap), schists, gneisses, &c., are proportionately most plentiful in the Basement Clay; while boulders from the Carboniferous area of the north-west, though everywhere predominant, are most strikingly so in the higher clays and gravels. The researches of Mr. Alfred Harker have proved that most of the basaltic rocks included in my lists have had their source in the sills and dykes of the Carboniferous, while the bulk of the granitic and gneissic specimens "might have been derived either from Scandinavia or from the Scottish Highlands. Among them are some undoubted Norwegian rocks, while none can be pointed out as *certainly* brought from Scotland. It may well be, then, that the whole of the doubtful rocks are also of Norwegian origin" *.

Mr. Harker summarizes the result of his examination of my Flamborough-Head specimens as under:—

"i. Among the boulders examined are some certainly from the south and west of Norway.

* Alfred Harker, 'Petrological Notes,' Proc. Yorks. Geol. & Polytechn. Soc. vol. xi. (1890) pp. 300–307, and *ibid.* pp. 409–423.

"ii. Most of the granitic, gneissic, and crystalline schistose rocks are referred with probability to the same source.

"iii. Other boulders have been furnished by the northern and eastern parts of the English Lake District.

"iv. Others have been derived from Teesdale; and

"v. Others again have come from the Cheviot Hills and the southern part of Scotland" *.

It is probable, however, that these boulders have not all been carried direct from the place of their origin to their present position by land-ice. We have such convincing evidence that portions of a boulder-strewn sea-bed † were, in some fashion or other, torn up and carried forward, with all their débris, during the formation of the Basement Clay, that it is evident the transportation of many of these blocks may have been a very complex matter. They may have been carried far by floating ice, and have rested long on the sea-bottom before being finally removed and mingled with the material amid which we now find them ‡.

My table shows in most points a fundamental agreement between the different lists; the proportion of far-travelled igneous and metamorphic rocks remains always very low and yet has the narrowest range of variation; blocks from the Carboniferous are always far more numerous than we might expect, considering the distance of the localities from the borders of that system, which are eighty or a hundred miles distant; and if we eliminate the effect of the varying number of the Secondaries in estimating the proportion, we shall find that this remains fairly constant for the Carboniferous rocks also. It is the Secondary rocks which form the unstable factor of the lists, both in proportion and in composition; and the strikingly low percentage of these rocks on Flamborough Head demands explanation. It is no doubt due to the bold eastward protrusion of the headland obliquely to the general direction of the ice-movement, a point which will be further discussed in the final part of this paper.

## VI. Classification of the Drifts.

From the foregoing descriptions it will be evident that the beds above the Chalk on the headland may be conveniently arranged under the following heads:—

| | | |
|---|---|---|
| 1. | Alluvial wash, freshwater marls, &c. | Recent. |
| 2 *b*, 2 *c*. | Late-Glacial gravels, brick-earth, and Boulder-clay. | Glacial. |
| 3, 3 *a*. | Upper Boulder-clay. | |
| 3 *b*, 3 *c*. | Intermediate Series; stratified beds, with bands of Boulder-clay. | |
| 4. | Basement Boulder-clay. | |
| 5. | Chalky Rubble. | |
| A, B, C. | "Infra-Glacial" beds of Sewerby and Speeton. | |

* *Op. cit.* vol. xi. p. 422.

† See Quart. Journ. Geol. Soc. vol. xl. (1884) p. 317.

‡ Mr. Clement Reid observes the same conditions with respect to the boulders in the Cromer Till, Geol. Survey Mem. 'Cromer,' p. 90.

The value and equivalents of these divisions will now be considered.

1. *The "infra-Glacial" Beds.*—Starting with the lowest beds, we are met at the very outset by a debatable question of the highest importance. Are these beds of Sewerby and Speeton, being older than the Basement Clay, to be considered as older than the Glacial period, or are they, as has been argued *, of inter-Glacial age, formed during an interval between two periods of glaciation?

My own opinion, as set forth in a recent paper †, is that the Basement Clay represents the earliest glaciation which affected the eastern side of England, and therefore that the formation of the beds which lie below it preceded that glaciation, though the interval between them may have been brief.

As to the physical conditions of the period, the "infra-Glacial" deposits indicate an open sea running in farther west on both sides of the headland than at present, a bare chalk wold, and a moist and comparatively mild climate. The fauna of the beds, as at present worked out, in spite of the abundance of specimens, is unfortunately rather meagre in species, as the following lists will show:—

*Fossils of the Sewerby Cliff-beds* ‡.

*Elephas antiquus*, Falc.
*Rhinoceros leptorhinus*, Cuv.
*Hippopotamus amphibius*, Linn.
*Cervus* (? *megaceros*, Hart).
*Bison*, sp.
*Hyæna* (*crocuta*, var. *spelæa* ?), Goldf.
*Arvicola amphibius*, Linn.
Birds.
*Gadus morrhua*, Linn.

| Land Mollusca. | Marine Mollusca. |
|---|---|
| *Helix hispida*, Linn. | *Purpura lapillus*, L. |
| *Helix pulchella*, Müll. | *Littorina littorea*, L. |
| *Pupa marginata*, Drap. | *Ostrea edulis*, L. |
| *Zua subcylindrica*, Linn. | *Mytilus edulis*, L. |
| | *Pholas* and *Saxicava*, indicated by borings. |

* Survey Mem. 'Holderness,' pp. 48 and 69.

† 'Glacial Sections near Bridlington,' pt. iv. *supra cit.*

‡ 'Final Report of the Committee,' &c., Brit. Assoc. Reports for 1890 (Leeds). *Elephas primigenius* appeared in one of the earlier lists, but proved to be based upon an erroneous determination. The above list has been verified, so far as the Mammals are concerned, by Mr. E. T. Newton.

*Fossils of the Speeton Shell-bed* *.

*Tellina balthica*, L.
*Scrobicularia piperata*, Gm.
*Cardium edule*, L.
*Mytilus edulis*, L.
*Littorina littorea*, L.
—— *rudis*, var., Maton.
*Hydrobia ulvæ*, Pen.
*Utriculus obtusus*, Mont., var. *pertenuis*.

There is nothing in either of these lists to afford more than an approximate idea of the age of the beds. I believe all the species contained in them date back to pre-Glacial times, but are also all present in later beds, and the collection is such as might occur anywhere between the commencement and the close of the Glacial period. The mammals found at Sewerby do not include any of the characteristic pre-Glacial species of the Norfolk "Forest-bed series," and bear a closer resemblance to those which occur in some "inter-Glacial" localities †; but as the ice itself could not bring the fauna, and the species must have been in existence somewhere throughout the Glacial period, this does not count for much. It is essentially the fauna of the Kirkdale Cave, which was considered by Phillips ‡ to be pre-Glacial. The presence of *Tellina balthica* in abundance at Speeton, on the other hand, shows that the beds were laid down in a period not far removed from Glacial times.

The evidence other than that of the fauna is also somewhat conflicting and uncertain. Along with the chalk pebbles in the Sewerby Beach there are a few foreigners which, though their proportion to the local rock is infinitesimally low, are yet of such diverse and far distant origin that they can scarcely have reached this shore except by the help of ice in some form or other. I collected these pebbles during an excavation of the beds, and have compiled the following list to show their character:—

*Pebbles in the Sewerby Beach* §.

| | | Per cent. |
|---|---|---|
| Carbonaceous Shale of uncertain origin ... | about | 10 |
| Sandstone of various kinds .................... | ,, | 25 |
| Quartzite .................................... | ,, | 20 |
| Palæozoic (?) Conglomerate.................... | ,, | 3 |
| Vein-quartz .................................. | ,, | 4 |
| Basaltic rocks................................ | ,, | 17 |
| Felsitic Porphyry, &c. ....................... | ,, | 13 |
| Granite ...................................... | ,, | 2 |
| Oolitic Limestone............................. | ,, | 4 |
| Black and yellow Flint (not local)............ | ,, | 2 |
| | | 100 |

* These are the species in my own collection (see Geol. Mag. (1881) p. 177). I have recently seen in the collection of Mr. R. S. Herries a brachiopod, *Rhynchonella psittacea*, Chemn., from this bed.

† The elephant-remains, however, from the gravels of Holderness which lie between the two Boulder-clays appear generally to belong to *Elephas primigenius*, while all which have yet been found at Sewerby have been determined as *E. antiquus*, and this seems to indicate a certain degree of change in the fauna of the locality in the interval covered by the Basement Clay.

‡ 'Geol. of Yorks.' 3rd ed. pt. i. p. 169. § See Brit. Assoc. Rep. quoted above.

These pebbles are generally of small size, say between that of a walnut and a clenched fist; but a few larger examples were found, the largest being a boulder of basalt 12 by 5 by 3 inches, and another, subangular, of porphyritic felstone 7 by 4 by 3 inches. Most of the pebbles were well rounded, but a few were subangular. One striking difference is apparent between these pebbles and the erratics of the overlying drifts; for while in the drifts of this locality fully 80 per cent. of the stones have been derived from the Carboniferous rocks, Mountain Limestone being particularly abundant, no Mountain Limestone nor other recognizable Carboniferous rock was found among the pebbles of the old beach. From this it would appear that at any rate no glaciers from the Pennine chain, by which the Carboniferous débris of the drift seems chiefly to have come, reached the east coast at this time.

Though there can be little doubt of the ice-borne character of these pebbles, it is an open question whether they have been carried to this beach by floating ice or have been derived at second hand from an older glacial deposit. If the latter view be correct the Cliff-beds may well be considered inter-Glacial; but I think that the evidence tends to show that it is not correct.

If the supposed earlier Glacial deposits capped the old cliff, traces of them could scarcely fail to appear in the landwash, in which, however, there are no erratics; while the difficulties which arise in supposing that such beds were submerged off the coast beyond the Chalk platform are very great. If there had been in Yorkshire an inter-Glacial period of so long duration as to allow the sea to cut back a line of hard chalk cliffs with a broad tidal platform at their base, its effect in other areas must have been equally marked. Yet I am aware of no evidence for such an interval among the drift-deposits of the east of England. Traces of a line of buried cliffs, evidently the continuation of that of the Sewerby section, have been found along the inner edge of the Wolds, not only along the Holderness margin *, but also in Lincolnshire †, the more southerly localities being within thirty or forty miles of the Norfolk coast. But in every case the drift is found to be banked against and over these cliffs, and no evidence is forthcoming for the existence of a Boulder-clay prior to the erosion of this old coast-line.

It is, I think, generally agreed that the Norfolk sections contain in the Forest-bed series and the overlying marine and freshwater horizons the fullest record extant in England of the period immediately antecedent to the Great Ice Age, and also of the earlier stages of the glaciation in the Cromer Till. But where in these sections shall we find above the Cromer Till a horizon to correspond with this of the Buried Cliff? Certainly not in the so-called Middle Glacial (which I believe to be closely analogous to the Intermediate Series of Yorkshire), whose accumulation must have taken place under conditions altogether different; and at any higher level there is nothing in the slightest degree comparable.

* Geol. Survey Mem. 'Holderness,' p. 65.

† Geol. Survey Mem. 'East Lincolnshire,' p. 78; and A. J. Jukes-Browne, Quart. Journ. Geol. Soc. vol. xli. (1885) p. 116.

We are compelled, then, to seek a marine horizon below the Cromer Till, and there, I think, may possibly recognize an equivalent in the "*Leda-myalis* bed" of the Geological Survey*. To this correlation no objection can be raised on the score of levels or conditions of accumulation, and with it the marine fauna of Speeton and Sewerby, so far as it goes, agrees remarkably well; while as for the transported pebbles, such pebbles are, I believe, not absent from any Norfolk marine gravel newer than the Red Crag, and occur rather plentifully in beds as low as the Weybourn Crag. And as these pebbles have probably been carried by floating ice drifting southwards upon the North Sea, the effect of the difference of nearly a degree and a half in the latitude, and the position of Sewerby under the lee of the prominent headland, may well account for their greater abundance in that locality.

Moreover, as will presently appear, there are very strong grounds for believing that the Basement Clay represents the oldest actual glaciation of the area. But the configuration of the district is such that it could not be invaded by land-ice until long after the commencement of glacial conditions; and therefore, though the marine beds of Sewerby and Speeton may not be strictly pre-Glacial, they nevertheless, I think, contain the record of a period anterior to the commencement of the glaciation of the east coast, and may be as old as the *Leda-myalis* bed of Norfolk.

It is not improbable that at the same period, in some other part of the North-Sea basin, the shelly sands were being deposited which were afterwards to be torn up and redeposited as part of the Basement Clay at Bridlington, Dimlington, and other places.

2. *The Chalky Rubble* (5).—Passing now to the consideration of the overlying drifts, we arrive first at the Chalk Rubble below the Basement Clay. The connexion between this bed and the Basement Clay is in some places so close as to indicate that their formation must have been, to a certain extent, contemporaneous. Yet in other sections, especially in the buried valleys, well-stratified sand or silt intervenes between them, as though there had been a well-marked change of conditions after the deposition of the rubble (see Pl. XIII. figs. 5 and 7). The Danes' Dyke section yields important evidence on this point, for there, as pointed out by Dakyns †, three different seams of chalky gravel touch the Chalk slope in succession as the lower beds die out (fig. 5), thus showing that the rubble may not all have accumulated at the same period. But erratic boulders and pebbles are occasionally present in the lowest bed, the true fine-grained "chalky wash," even where overlain by stratified warp and sand (Danes' Dyke and Pigeon Hole), and I am inclined to think that this fine-grained rubble, though perhaps actually accumulated on land by subaerial action, has yet been greatly modified and partially re-arranged during the passage of the ice. From the physical character of the district and its distance from high mountains, there must, as above mentioned, have been a long interval

* 'Bure Valley Beds' of S. V. Wood; 'Westleton Beds' of Prestwich.

† 'Glacial Deposits north of Bridlington,' Proc. Yorks. Geol. & Polytechn. Soc. vol. vii. (1880) p. 251.

before the ice-sheet reached this area, during which a severe climate was acting upon the exposed surfaces of chalk, so that a considerable thickness of disintegrated rock may have been formed upon the surface. This would be swept down into the hollow places during the summer floods, for the frozen condition of the upper layers of the Chalk probably prevented the ready absorption of surface-water. In the inner recesses of the Wolds, never reached by the North Sea ice-sheet, a similar deposit, often of considerable depth, has accumulated in high-lying depressions, as at Middleton, Huggate, and Mowthorpe *, and also in the upper reaches of some of the Wold valleys †; and has remained unmodified. But within the area invaded by the ice-sheet this surface-deposit could scarcely remain undisturbed, and under such conditions it may have occasionally had erratic blocks and pebbles incorporated with it, as at South Sea Landing and other places, while the Chalk was sometimes contorted below it, as at Danes' Dyke ‡. Its presence below the Basement Clay at Bridlington, 20 feet below sea-level, and its position in some of the buried valleys of the headland, point to an elevation of the land during its formation.

There is, of course, nothing peculiar to the locality in the occurrence of this rubble of the country-rock at the base of the drift-series; it is what is commonly seen in glaciated areas, especially on flat ground and at low levels §. But, whereas in most instances this rubble may be explained as the direct result of the grinding action of the ice-sheet, on Flamborough Head and on the Wolds generally such an explanation alone is quite inadequate to account for many of its features, and especially for the distribution of the deposit.

3. *The Basement Clay.*—I have shown in the foregoing description of the sections, and more fully in another paper ‖, that the Lower Clay of Flamborough Head is the northward continuation of the Basement Clay of Holderness. It is now quite clear that, though it includes the scrapings of a boulder-strewn Glacial sea-bottom with an Arctic fauna, the clay cannot on this account be reckoned marine, any more than it can be reckoned Liassic because of its inclusion of large quantities of Liassic débris. The presence of scratched (Filey) and contorted (Flamborough) rock-surfaces beneath

* See Rev. E. M. Cole 'On the Origin and Formation of the Wold Dales,' Proc. Yorks. Geol. & Polytechn. Soc. vol. vii. (1879) p. 131; and 'Note on Dry Valleys in the Chalk,' *ibid.* vol. ix. (1887) p. 344.

† J. R. Mortimer, Proc. Yorks. Geol. & Polytechn. Soc. vol. vii. (1881) p. 378, and Proc. Geol. Assoc. vol. viii. (1883) p. 287, also Geol. Survey Mem. 'Driffield,' p. 16.

‡ There is a close analogy between this chalky rubble and the 'Coombe-Rock' of the South Downs, and the views here put forward are essentially those adopted by Mr. Clement Reid to explain that deposit, in Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 364. The Coombe-Rock has not, however, been modified by subsequent glaciation, and is probably of newer date than the deposits under discussion.

§ *E. g.* T. Mellard Reade, Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 122; Jas. Geikie, 'Great Ice Age,' 2nd ed. p. 21, &c.

‖ 'Glacial Sections,' &c., part iv. *supra cit.*, which treats almost exclusively of this clay.

it, the absence of contemporaneous fauna from the associated stratified beds (other than the transported masses), the tumultuous character of its arrangement, and, above all, its distribution with regard to levels and to the shape of the ground show that, though the exact mode of its deposition may remain uncertain, it can scarcely be other than the direct product of land-ice. This ice seems to have crept in upon the land from the north-east, coming up out of the bed of the North Sea.

The physical conditions of East Yorkshire throughout the Glacial period seem to have been very favourable to the accumulation of deposits, so that the work of the ice in this, its peripheral area, has been to spread out successive sheets of material one over the other in rude stratification with very slight erosion of the underlying surface. This was, no doubt, partly because of the general absence of high elevations or steep confining boundaries and the presence of a wide and open outlet to the southward, conditions which must have attended every encroachment of the ice upon the district; and partly because the ice which reached this area was wasting rapidly, and had little erosive power so near its margin. These conditions must have affected every ice-flow in the region, and would have brought about a similar copious deposit from any earlier glaciation than that of the Basement Clay, had such occurred. No real evidence for the existence of such a deposit is, however, forthcoming, the Basement Clay and its associated rubble forming the base of the drifts wherever in our sections a base is seen. It may be objected that there is in Holderness a considerable depth below the top of the Basement Clay about which we know nothing; but judging from the behaviour of this clay in the coast-valleys between Scarborough and Saltburn, where it frequently swells out to a great thickness (60 to 100 feet on the hollow ground), without much change in the level of its upper surface, I think it is most probable that this division extends everywhere downward to the Chalk, or to the gravels or pre-Glacial stratified beds which may rest on the Chalk. This view is sustained by such records as we possess * of the well-borings which have reached the Chalk in Holderness.

The very fact that the area could not be invaded by land-ice until the basin of the North Sea northward from Flamborough was quite filled up by the glacier furnishes a further argument. If there had been an earlier glaciation, then there must have been an accumulation of the ice to this extent; and this ice must afterwards have disappeared and remained so long absent that there was time for the Sewerby cliff-line to be carved out by the waters of an open sea. Of such a double glaciation of the North-Sea basin there is neither proof nor probability.

Still further evidence for the non-existence of earlier Glacial beds is furnished by the repeated occurrence of transported masses of Secondary rocks in the Basement Clay. These have been derived from various formations; the White and Red Chalk, Neocomian Clay, Kimeridge Shale, Upper and Lower Lias Shale, are all repre-

* Geol. Survey Mem. 'Holderness,' pp. 132–162.

sented, and prove, I think, that the marine deposits torn up by the Basement-Clay ice rested upon a platform of Secondaries and not upon older Glacial beds. Neither transported Secondaries nor shelly masses of sea-bottom have yet been observed in any of the higher Boulder-clays, a fact which seems to show that when these deposits were once hidden under the Basement Clay they were practically rendered inaccessible to the ice of the later glaciation.

I therefore concur in the later results of S. V. Wood * with respect to the Basement Clay, and regard it as the product of the earlier ("Major") glaciation, and roughly equivalent to the Cromer Till. One of the chief difficulties in the classification and correlation of the drifts of the North of England disappears if this view be correct.

That the Laminated Clay should, in its northward extension, partly pass into the Basement Clay (Pl. XIII. fig. 3) shows that the upper boundary of the Basement Clay is not so well defined as was at one time believed. The stratified bed seems indeed to form a passage from the Basement to the lower part of the Purple Clay, and is evidently no testimony for anything more than local conditions. And this new evidence causes me to think that it may perhaps be advisable, for the sake of convenience, to extend the upper limit of the Basement Clay in the Holderness coast-sections so as to include within it the band overlying the shelly clay, as seems indeed to have been done by Wood and Rome †.

4. *The Intermediate Series and Purple Boulder-clay.*—The origin and correlation of the beds between the Upper and Lower Boulder-clays on Flamborough Head constitute at once the most difficult and the most important of the problems of the sections.

I have shown that the Lower Clay is on the whole the prolongation of the Basement Clay of the Holderness coast, and shall also show that the Upper Clay is roughly equivalent to the capping Boulder-clays ("Hessle Clay") of that region. But the intervening beds seem at first sight to have little in common. In the Holderness sections, and even at Bridlington, we find, between these beds, bands of "Purple" Boulder-clay, sometimes showing distinctly stratified zones and sometimes lenticular seams of sand and gravel, which have, notwithstanding, as much right to be considered the product of land-ice as either of the other Boulder-clays ‡. But on Flamborough Head the beds between the Upper and Lower Boulder-clays consist, as the details of the sections have shown, of a complex and ever-changing series, often confusedly arranged, of silt, sand, gravel, and bands of Boulder-clay. This series sometimes seems to pass gradually downwards into the Basement Clay, but more often the junction is distinctly one of erosion. Its relation to the overlying Upper Clay is similarly variable,—one section revealing a gradual passage, while another shows displacement and erosion at the junction.

* 'The Newer Pliocene Period in England,' part ii., Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 668.

† Quart. Journ. Geol. Soc vol. xxiv. (1868) p. 148.

‡ Geol. Survey Mem. 'Holderness,' pp. 26–36.

The gravels of the series, sometimes chalky, sometimes chalkless, are arranged, as has been shown, in a kame-like chain of mounds. These beds are occasionally coarse and morainic, but more often are composed of fine and well-stratified material. A careful search among the gravels, and especially among the finer chalkless gravels, rarely fails to reveal crumb-like fragments of marine shells, or even, occasionally, scattered and much-worn valves, but nowhere have any organic remains been found in the beds of laminated silt, warp, or clay which abound in the sections, nor in the clean sands, where, if any contemporaneous fauna had existed, the remains should have been preserved. The shells which occur in the gravels are invariably the common species of the underlying Boulder-clay.

The sections immediately north of Bridlington Quay show clearly (see Pl. XIII. fig. 3) that, in spite of the apparent difference, these stratified beds are really equivalent to the Purple Boulder-clay, since we can trace the greater portion of the clay until it is shredded out and merged with bedded loam and gravel. At the same time it must be noted that this equivalence probably holds good only in a general way, for the lower part of the Purple Clay in the neighbourhood of Danes' Dyke seems to be merged into the Basement Clay, and, on the other hand, the Basement Clay passes up in places into the stratified beds; and similarly the Upper Clay in some of the Flamborough sections coalesces with what may be considered the topmost portion of the Purple Clay, just as it has been observed to do in some sections in Holderness * and in Lincolnshire †. But, broadly speaking, the great mass of the Purple Clay may be said to resolve itself, in the Flamborough sections, into stratified deposits.

The relationship thus existing between the Holderness and Flamborough-Head drifts is illustrated by the right-hand half of the diagram (Pl. XIII. fig. 15).

This demonstration of the passage of the Purple Clay into the Intermediate Stratified Series of Flamborough affords, I think, an explanation of the perplexing differences between the structure of the drifts on the coast-line of Holderness and in the interior. While Boulder-clays nearly everywhere prevail in the cliff-sections, the drifts of the interior, sometimes at a distance of only three or four miles, consist very largely of sand and gravel, usually arranged in kame-like mounds running in more or less continuous lines, generally nearly north and south, or otherwise roughly parallel to the course of the Wolds. These, in spite of certain differences presently to be mentioned, I consider to belong to the same system as the Gravel Range of Flamborough Head, and to have had a similar origin.

Hamilton Hill, near Barmston, a conspicuous feature in the low land within a few hundred yards of the coast, about three miles

* Geol. Survey Mem. 'Holderness,' pp. 33–35 & 43.

† A. J. Jukes-Browne, 'The Boulder-clays of Lincolnshire,' Quart. Journ. Geol. Soc. vol. xli. (1885) p. 127.

south of Bridlington, seems to be now the most northerly of the Holderness mounds, though I think there is evidence that others have existed still nearer to Bridlington *, and have been destroyed by fluviatile action and by the encroachments of the sea, which have once linked Beacon Hill (fig. 6) or Potter Hill (fig. 3) to the Holderness range. From Barmston the line may be followed inland (though not quite uninterruptedly) by Stonehills, Gransmoor, Kelk, Brigham, Frodingham, and Brandesburton. The structure of the mounds is evidently everywhere similar to that of Beacon Hill. They are based on Boulder-clay, and their flanks wrapped by an upper red Boulder-clay which generally thins out before reaching the crest of the hill †. In southern Holderness the range becomes broader and more complex and broken, and may have been formed under somewhat different conditions.

In going southwards from Barmston shell-fragments occur in the gravels in constantly increasing numbers; but until we reach the neighbourhood of the Humber the species are always the same as those that occur at Flamborough, though *Cardium edule* becomes relatively more abundant.

These beds have been described as "marine gravels of interglacial age" (Geol. Survey Mem. "Holderness"), apparently chiefly because of the presence of shell-fragments in them, but I think that, at any rate in Northern Holderness, they can scarcely have had a marine origin. Even where the shells are most plentiful, the valves are always separate, unbroken specimens very rare, and all much waterworn; moreover they all occur among the fine gravel, and none in the silty beds. I believe that a section east and west across Holderness would reveal the passage of the Purple Clays into these beds (as shown in the left half of the diagram, fig. 15), just as the north and south cliff-section reveals the passage of the clays into the stratified beds of Flamborough Head.

The position of the Intermediate Beds on the crest of the escarpment at Speeton has arrested the attention of many observers. They were first described by Wood and Rome as "denudation gravels of post-Glacial age," and supposed to have been formed during a great submergence ‡. But it is so extremely improbable that a marine gravel could have accumulated in such a position that we are not surprised to find S. V. Wood, in his later memoir §, refer them (in parenthesis) to "the melting there of the Purple-Clay ice." This latter explanation I believe to be the true one, and, as I have already mentioned, the opinion of the late Prof. Carvill Lewis was essentially the same.

With ice filling up the bed of the North Sea to the extent indi-

* The sandy rising ground on which Hilderthorpe stands probably belongs to this range, having been eroded and its outline destroyed during the formation of the recent freshwater gravels, &c., which surround it.

† See Geol. Survey Mem. 'Holderness,' pp. 52–53. The beds are described as 'Marine Interglacial Gravels,' see above; also 'Driffield,' pp. 14 & 15.

‡ Quart. Journ. Geol. Soc. vol. xxiv. (1868) p. 175.

§ *Ibid.* vol. xxxvi. (1880) p. 520.

cated by the Basement Clay, and this ice not of local origin but an extraneous mass (for it is clear that the Yorkshire Wolds and the eastern moorlands added nothing to it, and were not entirely submerged by it), there must have been a time when the great sheet rested with its flank upon this bold coast-line while its main current swept southwards, following the deepest part of the sea-bottom. The basin of the North Sea has been so greatly modified by material deposited in it during Glacial times that it is not possible now to trace its pre-Glacial features. But there are reasons for supposing that the deepest hollow lay at some distance from our coast *, especially south of Flamborough, and therefore that the main ice-current would probably flow southwards unimpeded by the coast-line, while only the right wing of the great glacier, augmented by the Teesdale and other Pennine ice, expanded sluggishly westward upon our shores. At the time of its greatest extension the ice seems to have been five or six hundred feet thick at Speeton, and a thin flange from the top of the glacier probably passed, during the deposition of the Basement Clay, over the crest of the cliff there, and made its way down the Bempton valley; meanwhile the chief portion was deflected eastwards along the line of cliffs, bearing hard upon the bottom and tearing up the Speeton Clay in its course, because of this obstruction, until it reached the lower ground near Flamborough, which it overrode.

Forty miles farther north, in the neighbourhood of Whitby, the ice seems during its greatest extension to have reached a height of about 800 feet above sea-level †. But south of Flamborough, as the effect of the shelter afforded by the headland, and probably also because of the shallowness of the Bay of Holderness and the distance of its shores from the main current of the glacier, the level attained by the glacial deposits, and therefore presumably by the ice, sinks at once to between 200 and 270 feet ‡, and does not again exceed this elevation north of the Humber. In South Lincolnshire, however, where the Wolds protrude eastward again, and would therefore lie more directly in the path of the ice, the current seems to have overridden them in places where they are as high as 400 feet above sea-level §. I regard these differences of level as strong evidence for the "land-ice" origin of the drifts, and also for the stability of the *relative* levels of the east of England during the Glacial period.

So long as the edge of the ice was advancing, no great accumulation of material could very well take place at its margin, for anything lodging in front of it would soon be overridden and mingled with the basal moraine. But as soon as its growth was arrested and it began to decline there must have been considerable deposition in

* During part of the Pliocene period the bed of the North Sea seems to have been dry land, wherein the Rhine and Thames united to flow northwards (Geol. Survey Mem. 'Cromer,' p. 57). The river-valley then eroded would probably lie at some distance from the Yorkshire coast-line.

† Geol. Survey Mem. 'Geol. of Eskdale, &c.,' p. 51.

‡ Geol. Survey Mem. 'Driffield,' p. 13.

§ A. J. Jukes-Browne, 'The Boulder-clays of Lincolnshire,' Quart. Journ. Geol. Soc. vol. xli. (1885) p. 117.

this quarter, by the washing of débris off the ice, and from the land also, where the ground sloped towards the glacier. Under such conditions thick mounds of stratified drift, like those on the escarpment at Speeton, might be piled up by surface-waters coursing down the marginal slopes of the glacier.

Quite favourable to this view are the alternations of chalky and chalkless gravels at the lower levels of the headland. With the glacier to the north and east sending, in summer, streams laden with drift detritus into the ice-dammed hollows on its flanks, and to the westward the bare Chalk Wolds weathering rapidly and supplying a fresh burden to every flood, the interstratification of beds of varying appearance near the margin of the glacier can be readily understood.

It is clear that the ice which formed the Basement Clay must have been charged with marine débris * (caught up by some method not yet, perhaps, clearly explained), and wherever the solid residuum of that ice has accumulated, whether as Boulder-clay or as gravel, traces of the marine deposits destroyed by it are almost certain to occur, precisely as we find traces of the other older deposits which the ice has similarly laid under contribution. The presence of these shell-fragments in the gravels is therefore no more proof of the marine origin of the beds than the Liassic or Carboniferous fossils are proof of their Carboniferous or Liassic age †. And the greater abundance of the fragments generally, and of *Cardium edule* in particular, at the lower levels in North Holderness is exactly what we might expect to find after the ice had passed across a sandy bay ‡, such as we know to have existed there.

To the washing of morainic material at the margin of the ice, then, may be ascribed the origin of the Intermediate beds of Flamborough Head and of the north of Holderness.

With regard, however, to the deposits of this age in the neighbourhood of the Humber, it is possible that here the pre-existing marine beds may not have been so greatly modified by the action of the ice, and that the sea was not altogether shut out by the glacier during the formation of the gravels. In the well-known Kelsea-Hill pits, the shells are present in far greater numbers and in much better preservation than farther north, and include *Cyrena fluminalis* and other peculiar species. But even here, though I have examined the section many times, I have never felt convinced that the shells represent a contemporaneous fauna. The general character of the

* Geol. Mag. (1890) p. 67.

† There is, of course, nothing new in this argument, which has been frequently applied to account for the presence of shells in glacial gravels, as for instance by Mr. H. B. Woodward in discussing the 'Middle Glacial' of Norfolk (Proc. Geol. Assoc. vol. ix. (1886) p. 111); Mr. T. F. Jamieson for shelly gravels in Aberdeenshire (Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 145), which seem to bear a very close resemblance to the Flamborough beds; T. Belt ('Nature,' May 14, 1874) and various other observers, for the Moel-Tryfaen and Macclesfield beds; and the late Prof. H. Carvill Lewis for the drifts generally, Rep. Brit. Assoc. (1887) p. 692.

‡ As shown by the blown sands of the Sewerby Cliff.

deposit, with its innumerable subangular flints (mostly not of local origin) and other boulders, the arched bedding, the absence of shells from the silty seams, the eroded and scattered character of all the specimens, and the curious mixture of forms, do not suggest ordinary marine action. Moreover, in another pit on the same ridge about one mile north-north-east of Kelsea Hill, I noticed recently an irregular bed of stony clay one foot in thickness in the heart of the shelly gravels *.

On the opposite side of the Humber, eight miles farther west, at Kirmington in Lincolnshire, there is indeed an undisturbed estuarine deposit of muddy silt, with bivalves of three or four species and a few other remains of an undoubtedly contemporaneous fauna, which is usually considered of the same age as the Holderness gravels †. But the evidence for the correlation is by no means convincing, and it seems to me more than probable that the bed may be a portion of an older deposit, like those at Sewerby and Speeton, which has escaped destruction.

And, while admitting that on the whole there is stronger evidence for the presence of the sea during the formation of the mounds in Southern than in Northern Holderness, I still find it difficult to believe that deposits which are apparently conterminous, and have so many features in common, should have had a widely different origin. The solution may perhaps be, as suggested above, that the sea was not entirely excluded from the old bay, and in some places laved the edge of the glacier ‡.

My conclusion, therefore, is that the Intermediate series of Flamborough Head and of Northern Holderness was formed at the edge of the ice during a period of slow recession following a long pause; that, while these beds were being deposited at the margin, the formation of Boulder-clay was still going on over the area covered by the glacier; and that thus the Purple Clays of the Holderness coast were laid down contemporaneously with the stratified beds of the interior and of Flamborough.

There must have been during this period, as the late Prof. Carvill Lewis pointed out, a great accumulation of fresh water in the valleys whose mouths were blocked by the North-Sea ice. Most of the eastward-draining Yorkshire valleys would be in this condition, and these bodies of water must have brought about the deposition of large quantities of stratified débris, washed into them from the land on one side and the ice on the other. Many of the gravels of Flamborough Head, especially those on the lower southern side, seem, as we have seen, to have been thus deposited. Farther north, in the deep valleys of the Oolitic moorlands which lie open to the

* Prof. Jas. Geikie observed Boulder-clay among the gravels at Kelsea Hill, but had good reason for supposing it to be a tongue thrust out from the main mass ('Great Ice Age,' 2nd ed. p. 378, figs. 59, 60). The above-mentioned case, however, could not be thus explained, as the clay is 10 or 12 feet deep in gravel, and there is no overlying Boulder-clay.

† Geol. Survey Mem. 'Holderness,' p. 58.

‡ Just as the sea re-sorts the morainic and freshwater gravels on the flanks of the Muir and other glaciers in Alaska.

sea, the result of these conditions is still more marked. From this cause may arise the rapid increase in the proportion of gravel to clay as the drifts approach the hilly ground *.

If the relation of the Purple Clay to the Intermediate beds be such as I have described, it is evident that the replacement of the one by the other will rarely be suddenly marked, but will take place gradually, as the beds are traced across the space once occupied by the ice-margin. So also the limits of the Lower and of the Upper Boulder-clays will be only more or less vaguely definable.

The cause and the extent of the recession indicated by the stratified beds will be more conveniently considered in the next section, wherein the Upper Boulder-clay is treated of.

5. *The Upper Boulder-clay.*—The distinguishing features of the Upper Clay of Flamborough Head are that it is redder in colour, more earthy and less compact in texture, and less irregular in thickness than the lower division, and has fewer boulders. As already mentioned, it evidently comprehends the top clay of Holderness (the "Hessle Clay" of Wood and Rome), that deposit being by no means the "low-level" or valley deposit which those authors supposed †. Its limits on Flamborough Head and elsewhere need not, however, be strictly the same as those of the Holderness bed. It is decidedly thicker at low elevations, but is persistent over the high ground on the north face of the headland, where the Basement Clay apparently sometimes dies out (Pl. XIII. fig. 11). Its westward limit on the Wolds cannot be clearly traced, but seems to depend more on the proximity of the range of gravel-mounds than on either the shape or elevation of the surface. Though the identification is perhaps not quite convincing, it seems to be this clay which covers thinly and interruptedly the inner edge of the Wolds, beyond the limits of the gravels, up to elevations of 250 feet ‡ almost everywhere between Flamborough and the Humber. Even at low elevations it seems sometimes to be replaced by stratified beds, as on both sides of Bridlington Quay, and in a few sections in Holderness; and it frequently shows a tendency to pass into the underlying gravels. In many respects it bears a close analogy to the "Fringe" or "Extra-Morainic Boulder Clay" of America, whose origin has given rise to so much discussion among Transatlantic glacialists. I do not see how it can have been formed except by land-ice, but it hardly bears the characters one would expect in a basal moraine, and I am tempted to apply to it the theory of the origin of Boulder-clays so ably advocated by Mr. J. G. Goodchild § in England, and Prof. A. H. Winchell and others in America ||, and to regard it as

* See S. V. Wood, Quart. Journ. Geol. Soc. vol. xxxvi. (1880) p. 503.

† Quart. Journ. Geol. Soc. vol. xxiv. (1868) p. 151.

‡ Geol. Survey Mem. 'Driffield,' p. 13.

§ Quart. Journ. Geol. Soc. vol. xxxi. (1875) p. 99; Geol. Mag. (1874) p. 496; Trans. Cumberl. & Westmorl. Assoc. Lit. & Sci. vol. xii. (1887) pp. 111 *et seqq.*

|| Jas. Geikie, 'Great Ice Age,' 2nd ed. p. 460.

the residuum left behind on the melting of a sheet of ice charged with clay and stones. This theory certainly accounts for many features in it which are otherwise difficult of explanation, such as its uniform texture, its relation to the stratified deposits along drainage-channels, its extension beyond the limits of the rest of the drift, and its behaviour on the Chalk slopes and on the flanks of the gravel-mounds. But setting aside this debatable question as being too wide for full discussion in this paper, while accepting for the clay, as most have done who have studied it *, an origin in some way or other the result of land-ice, its composition and distribution seem necessarily to postulate the continued blockade of the North-Sea basin by an ice-sheet during its formation. The abundant fragments of Carboniferous and other North-Country rocks contained in it at Flamborough, together with the absence of the clay from the higher and from the westward part of the Wolds, show that the Teesdale ice has still come coastwise, and not across the Wolds; and for that ice to have taken such a course necessarily implies the presence of some great obstacle barring its passage eastward in the North-Sea basin. This ice, in coming down the coast north of Flamborough, seems to have been shouldered in, as it were, upon the land, and sometimes forced up into the open valleys of the Yorkshire coast. Hence the predominance of Carboniferous rocks in the drifts of the headland and the country to the north of it, as shown in the Boulder lists.

This could scarcely have taken place had not the North-Sea glacier still held its ground; and it would appear, therefore, that the retrocession indicated by the stratified series went no further than, at the most, to carry the margin of the ice back a few miles from our coast, the character of the junction between the Intermediate beds and the Upper Clay being frequently such as to show gradually changing and alternating conditions without any considerable interval of interruption. And that the Upper Clay should extend beyond the limits of the older drift seems to indicate that in the later stages of the Glacial period, while the North-Sea glacier was gradually diminishing, there was a great augmentation in the quantity of ice flowing from the Pennine chain †, which was pent in upon the east coast and overstepped the old moraines. At a later stage the continued decadence of the North-Sea ice may at length have opened a path due eastwards for the Teesdale and other North-British glaciers, whereupon the coastwise current, being tapped at the source, would suddenly cease; and the East Yorkshire branch, receiving no fresh supply, would become

* S. V. Wood's later papers; Mr. Clement Reid's 'Holderness' Memoir, p. 42; Prof. Jas. Geikie's 'Great Ice Age,' 2nd ed. p. 374.

† The wide obliteration of the open-water surface surrounding Scandinavia and the northern portion of our own islands through the encroachment of the ice-sheet would probably shift westwards the area of greatest precipitation, and, as the ice-flow must always be dependent on the snowfall, this may have brought about the conditions noted above. (See abstract of 'East Yorkshire during the Glacial Period,' in Rep. Brit. Assoc. 1890).

in places nearly stationary, and thaw gradually away, leaving its solid contents in the form of the Upper Clay.

6. *The Sewerby Gravels and Newer Beds.*—These beds need little further discussion. As already suggested, the "Bridlington Series" (Sewerby Gravels and Hilderthorpe Sands) seems to replace the Upper Clay, and to have been deposited at about the same period as that clay by strong currents of fresh water issuing from the Main Wold Valley, perhaps dammed back by the ice which may still have covered the eastern part of Holderness *.

On the outskirts of Bridlington Quay are newer gravels (the "Gypsey Gravels") evidently deposited at a still later period by a reduced though yet considerable volume of water from the same valley, when the stream had no direct route to the sea and turned southwards to seek the Humber (see p. 388).

Similar gravels are found at the mouths of most of the Wold valleys opening upon Holderness, as at Lowthorpe, Driffield, &c.†, and indicate a climate very different from that of to-day. I have suggested ‡ that they were formed when the winters were so severe that the upper layers of the Chalk were choked with water and permanently frozen, thus rendering the rock impervious so that it shed off the water torrentially § during the summer thaw. It was at this period that the excavation of the now dry Wold valleys was completed. At Bridlington these gravels are occasionally interbedded with peaty silt and freshwater marl, and are proof that the area has not suffered marine submergence since the Glacial period.

## VII. Notes on the Correlation of the Drifts.

That this investigation should have led to the adoption of a tripartite division, as the most natural and the most convenient, not only for the drifts of Flamborough Head, but also of Holderness, is really, in the main, no more than a confirmation of the work of the earlier observers. John Phillips ‖ seems from the first to have been of this opinion ; so also, for the drifts north of Flamborough, Martin Simpson ¶, and the officers of the Geological Survey of the coast between Scarborough and the Tees **. The difficulties which afterwards arose were chiefly owing to the theory of Wood and Rome, that the "Basement Clay" was confined to Southern Holderness

* See 'Glacial Sections,' part iii. *supra cit.*, for full details of these later beds.

† Geol. Survey Mem. 'Driffield,' p. 15.

‡ Proc. Yorks. Geol. & Polytechn. Soc. vol. viii. (1883) p. 249.

§ It has since been shown by Rev. E. M. Cole, F.G.S., that this effect is still occasionally produced on the Wolds when a sudden thaw follows a very severe frost ; see 'Note on Dry Valleys in the Chalk,' Proc. Yorks. Geol. & Polytechn. Soc. vol. ix. (1887) p. 343.

‖ 'Geology of Yorkshire,' 3rd ed. pt. i. p. 163.

¶ Geol. & Nat. Hist. Repert. (1865) vol. i. p. 57.

** Geol. Survey Mems. 'North Cleveland,' by G. Barrow, p. 65 ; 'Whitby and Scarborough,' by C. Fox-Strangways and G. Barrow, p. 52 ; 'Eskdale,' by C. Fox-Strangways, G. Barrow, and C. Reid, p. 51 ; also 'Northallerton and Thirsk,' by C. Fox-Strangways, A. G. Cameron, and G. Barrow, p. 54.

and that no older division than the Purple Clay existed on Flamborough Head and the coast beyond. Now, however, that this supposition has proved unfounded, and the Glacial deposits of the whole coast-line are shown to be closely related, the comparison of these drifts with those of other areas will have been greatly facilitated. Such comparisons between areas not actually conterminous are always beset with difficulties; but if it be allowed, as I think it must, that the glaciation of East Yorkshire has throughout been determined by ice extraneous to the district, it necessarily follows that very wide areas must have been simultaneously affected. We ought at any rate to be able to establish a correlation of all the East-Coast drifts south, say, of the Scottish border; and even of those on the low ground on the opposite side of England in the same latitude, except in the immediate neighbourhood of mountainous country, such as might be affected by the later local glaciers. To attempt such a correlation, however, would require a far longer study in the field of the details of other sections than it has been in my power to make. It is with considerable diffidence, therefore, that I put forward the following suggestions, which must be taken at what they are worth.

In the eastern parts of Northumberland and Durham, and especially on the low ground bordering on the Tees, and south of that river *, a similar tripartite division of the drifts has been frequently observed, often with shell-valves and fragments of the familiar species in the stratified beds; and the difference between the Upper and Lower Boulder-clays seems to be very much the same as in East Yorkshire.

Almost everywhere in East Lincolnshire from the Humber to the Wash, two Boulder-clays, separated by sand and gravel containing shell-fragments, are found between the Wolds and the sea, though, as in Yorkshire, the Upper Clay is sometimes absent where the gravels are piled up in mounds †. The Lower Clay has generally been supposed to represent the Purple Clay of Holderness, but I think there can be little doubt that the structure of these areas, separated only by the Humber, is identical, and that the Lower Clay of East Lincolnshire is the Basement Clay.

In Norfolk, according to the later conclusions of S. V. Wood ‡, the Cromer Till should be considered the analogue of the Basement Clay; this seems to me most probable, the agreement between them in several essential points being very close. The Contorted Drift and "Middle Glacial" gravels together may represent the period of the Purple Clays of Holderness and Intermediate beds of Flamborough, and on this basis most of their characteristics may be explained. The Chalky Boulder-clay may then be taken as roughly equivalent to the Upper Boulder-clay of Yorkshire, though

* Geol. Survey Mem. 'Northallerton and Thirsk,' p. 54; and Prof. G. A. Lebour, 'Geology of Northumberland,' pp. 2 and 16, 1st ed. (1878).

† A. J. Jukes-Browne, Quart. Journ. Geol. Soc. vol. xli. (1885) p. 114; Geol. Survey Mems. 'East Lincolnshire,' p. 76, and 'Holderness,' pp. 56–63.

‡ Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 667.

this correlation, in spite of its having received the sanction of S. V. Wood, will not, I expect, be considered sound in view of the Mid-Lincolnshire evidence. However, after having examined some of the Lincolnshire sections, and after close study of much of the literature of the area, I am still inclined to endorse it.

In Lancashire and some other parts of the west coast the triple division of the drifts * corresponds very closely with that of Yorkshire in many important features, such as the frequent presence of a rubble of the local rock under the Lower Clay, the occurrence of shell-fragments in the Boulder-clay and in the intervening stratified beds, the differences in character and composition between the Lower and Upper Clays, and the general inconsistency and final disappearance of the stratified beds in certain directions.

Not that there is anything peculiar to the North of England in this tripartite arrangement of its Glacial deposits, for similar features seem to have been observed all over these islands, and indeed in almost every glaciated region, especially where the ground is low and flat. The concurrence is rendered the more striking by the fact that the bottom clay is almost invariably the darker in colour, usually dark blue, grey, or purple, while the top clay is as commonly reddish or yellowish. It has been suggested that such an arrangement is a necessary result of the action of land-ice when acting in wide sheets †.

From the foregoing account it will be gathered that in my opinion there is no good evidence in East Yorkshire for a mild inter-Glacial period, but that, on the other hand, the formation of the drifts, from the Basement Clay upwards, was directly dependent upon the presence of land-ice in the bed of the North Sea, and went on uninterruptedly, though with wide fluctuations of the ice-margin, to the closing stages of the period. But as the higher portion of the Wolds was never submerged, and their lower slopes not always covered, animal life may not have been entirely shut out from the region, and may have existed at times not far from the edge of the ice-field. The occurrence now and again of animal remains, in stratified beds formed near the borders of the glacier, can be thus explained without postulating the total disappearance of the ice ‡.

* D. Mackintosh, Quart. Journ. Geol. Soc. vol. xxviii. (1872) p. 388, &c.; T. Mellard Reade, *ibid.* vol. xxxix. (1883) p. 83, &c.; C. E. De Rance, *ibid.* vol. xxvi. (1870) p. 641; and Geol. Survey Mem. ' S. W. Lancashire.'

† Dr. O. Torell, Am. Journ. Sci. vol. xiii. (1877) p. 77; Warren Upham, Canad. Naturalist, vol. viii. (1877) p. 327, &c. It is remarkable how well the descriptions of some American Drift-sections would answer for others on this side of the Atlantic. See also Warren Upham on ' Work of Prof. H. C. Lewis,' in Geol. Mag. (1889) p. 159.

‡ Gravels of uncertain age, but apparently Glacial, yielding a few mammalian remains, occur in some parts of the East Riding, both East and West of the Wolds. See Geol. Survey Mem. 'Holderness,' p. 50; John Phillips, ' Geology of Yorkshire,' 3rd ed. vol. i. p. 13; and Proc. Yorks. Geol. & Polytechn. Soc. vol. ix. (1887) p. 407, for examples.

## VIII. Conclusion.

To bring together my views as to the physical conditions prevailing in this area during the formation of the drift deposits I suppose that:—

At a period not long anterior to that of the glaciation of the coast, Flamborough Head was in existence as a bold promontory jutting out into a sea whose level was slightly above that of to-day.

Most of the mammals characteristic of the Glacial period were already living, and tenanted the interior in large numbers. The climate was moist and not very severe, the prevalent winds, as shown by the sand-dunes of Sewerby, being from the west or south-west.

After the land had remained for a long time stationary, a slow elevatory movement set in, and the climate became much colder; so that the Chalk-surface was disintegrated by frost and eroded by sudden floods, which spread thick beds of muddy detritus over much of the low or slightly sloping ground in the vicinity. Meanwhile the bed of the North Sea was being rapidly filled with ice through the great extension of the Scandinavian glaciers; till at length the Scotch and Scandinavian ice coalesced, and what remained of the North Sea was well nigh ice-locked. The main current of this ice-sheet followed the deepest part of the sea-bottom southwards, at some distance from the coast but its flank, reinforced by ice flowing down Teesdale and other valleys in the North of England, spread westwards until it impinged upon the cliffs of Flamborough, and upon the slopes of the Wolds and Moorlands. It eventually rose higher than any portion of Flamborough Head, there attaining a thickness of at least 500 feet close to its margin. Where the cliffs were under 200 feet in height they were completely overridden by this ice, but where higher they split the current, sending one branch westwards for some distance into the Vale of Pickering, and the other south-eastwards along the cliff-line and finally southwards into the Bay of Holderness. The drainage channels of the streams flowing eastward were dammed by this ice, and lakes were formed, wherein deposits of gravel and other material rapidly accumulated. During this stage the Basement Clay was spread out.

Then followed a period during which the edge of the ice remained nearly stationary; and esker-like deposits of irregularly stratified material were formed along it. Afterwards, the North-Sea ice began to diminish, and its margin retreated for some distance, and fluctuated considerably. At this time the Intermediate Stratified Series and the Purple Clays were laid down.

Then another great advance of the glacier took place, but with ice chiefly from another source, the current being mainly composed of Pennine ice, though this was still hemmed in and held up by the North-Sea glacier. This ice overspread all the area occupied by the previous flow, and even extended beyond these limits; but the flow was of shorter duration, and seems to have been suddenly

arrested. Through the melting of this ice, the Upper Clay was deposited.

Finally, the rigour of the climate gradually abated, but for a long time after the disappearance of the ice the conditions of rainfall and drainage were very different from those of the present time.

## IX. Summary.

The chief conclusions of this paper may be summed up as follows:—

1. The Glacial deposits of Flamborough Head are best divided into a lower Boulder-clay; an Intermediate series, consisting chiefly of stratified beds; and an upper Boulder-clay.

2. The Lower Clay is a continuation of the Basement Clay of Holderness, and is the product of the first general glaciation of the area. The Intermediate series passes laterally into the Purple Clays of Holderness, and has been deposited at the edge of the ice-sheet. The Upper Clay represents broadly the topmost clay ("Hessle Clay") of the Holderness sections, and marks the close of the glaciation of this region.

3. The fossiliferous beds of Sewerby ("Buried-Cliff beds") and Speeton ("Estuarine Shell-bed") are older than the Basement Clay, and therefore than the earliest glaciation.

4. The glaciation was effected by land-ice of extraneous origin, which moved coastwise down the North Sea and did not overflow the greater part of the Yorkshire Wolds.

5. Neither the Boulder-clays nor the Intermediate Gravels are of marine origin, the shells which sometimes occur in them being derivatives.

6. The ice-sheet filled the North-Sea basin in this latitude from the commencement of the glaciation to its close. There is no clear evidence on Flamborough Head for a mild inter-Glacial period, but only for extensive fluctuations of the margin of the ice.

## EXPLANATION OF PLATE XIII.

Figs. 2–13 & 15. Sections in the Drifts on the south side of Flamborough Head, and Diagram to illustrate the supposed relation of the Drifts of the Holderness Coast to those of Flamborough Head, and of the interior of Holderness.

## Discussion.

Mr. Clement Reid congratulated the Society on receiving this evidence that a skilled geologist living on the spot was working out the difficult geology of Flamborough Head. While endorsing the Author's views as to the succession of the deposits shown in the cliff between Bridlington and Flamborough, he was unprepared to accept certain of the correlations made with South Holderness and Norfolk. In the first place there was no evidence that the so-called "Basement Clay" was really the oldest Boulder-clay deposited in Holderness, and he thought there was evidence, though scarcely conclusive, of an older glaciation. The correlation of the esker-like mounds of Flamborough with the fossiliferous gravels flanking the Wolds could not

be accepted, for the mapping of Holderness distinctly showed two independent gravels, the one marine and dipping regularly seaward beneath Boulder-clay till it sank beneath the sea-level, while the other capped the higher elevations near the coast, was coarse and irregular, and only contained fragments of shells washed out of the Boulder-clay, as is the case in the gravel-mounds of Flamborough.

The fauna of the marine gravels is such as might have lived at the spots where the fossils now occur. It is usually purely marine; but opposite the gap in the Wolds through which the Humber flows freshwater shells and bones of land-mammals occur abundantly, and freshwater shells are also found at one other spot, opposite the mouth of a Wold valley in North Lincolnshire. If the gravels had been pushed up and reconstructed by the ice, as suggested by the Author, it is curious that the slight variations in the fauna should agree so closely with variations in the local conditions where the gravel is now found, and not with variations we should expect to find farther seaward.

Mr. Whitaker asked if the "mounded gravels" might not be eskers, like some ridges of gravel seen in Western Norfolk, which had been thought to be eskers.

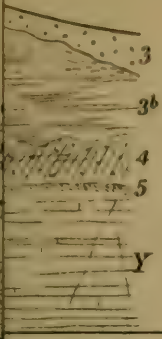
Mr. E. T. Newton pointed out that, although most of the species of mammals found at Sewerby were also found in the Norfolk Forest-bed, yet none of them were forms characteristic of that horizon; but, on the other hand, it was just such an assemblage of species as might be expected in an undoubted Pleistocene deposit.

Prof. Hughes, referring to the diagram on the wall, pointed out that much depended upon the establishment of the true relations between the Basement Clay and that represented as overlying the talus at the base of the cliff. If the talus were derived from the cliff against which it lay, the form of the cliff should be parabolic in section; but if the deposits now lying against the Chalk-face had slipped against a vertical sea-cliff, then the evidence as to their relative age from their present relative position was open to question. As the fauna agreed so closely with that of the gravels of Cambridgeshire, which could be proved to be post-Glacial, he was inclined to avail himself of any escape from the conclusion that it was of pre-Glacial or even Glacial age in Yorkshire.

The President remarked that he was reminded of an exploration of the Yorkshire coast made by him with Sir Andrew C. Ramsay, in the early days of glacial geology, when they examined many of the sections described by the Author of this paper. One of the observations which they made on that occasion was that, while many of the stones in the Boulder-clays might have come from the Scottish Highlands, there was a scarcity or absence of the rocks of the South of Scotland which ought to have been there, had the general mass of materials come from Scotland. These observations, which were not published, have been confirmed and extended by later writers, but the details of the drifts have never been so carefully worked out as they have now been by Mr. Lamplugh.

The Author said that he was quite prepared for the difficulties

Interval of 250 yds.

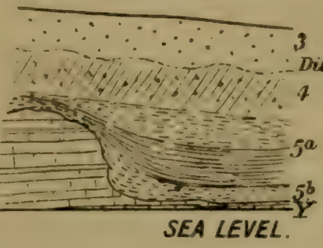



About two miles to extremety of headland

Fig. 7.

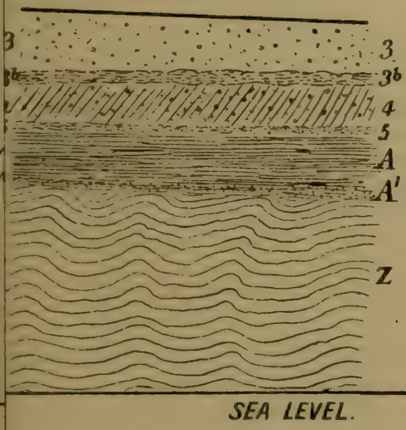
Cliff-Section on West Side of South Sea Landing.

Showing edge of Chalk hollow, with drift beds below Basement Clay.




Section on Middle Cliff Ridge, Speeton.

…owing Estuarine Shell-bed below the drifts.




## EXPLANATION OF DIAGRAM. Fig 15.

1 – Post-glacial & Alluvial beds.

2b – Sewerby Gravel.

3x – Hessle Clay of Holderness.

3a – Upper Purple Clay of Holderness.

} 3. Upper Clay of Flambro' and Interior

# Sections in the Drifts on the South Side of Flamborough Head.

Scale. One Inch to One hundred and twenty Feet.

Fig. 2. Cliff-Section opposite Albion Terrace, Bridlington Quay

Showing three, or four, separate Boulder Clays as in Holderness.


Fig. 3. Cliff-Section at Potter Hill

Showing passage of the Purple Clays into Stratified Beds and of the Laminated Clay into the Basement Clay.


Fig. 4. Cliff-Section at Sewerby.

Showing the Buried Cliff of Chalk with fossiliferous deposits banked against it.


Fig. 5. Cliff-Section at Danes' Dyke.

Showing stratified character of the Drifts in a buried hollow of the Chalk.

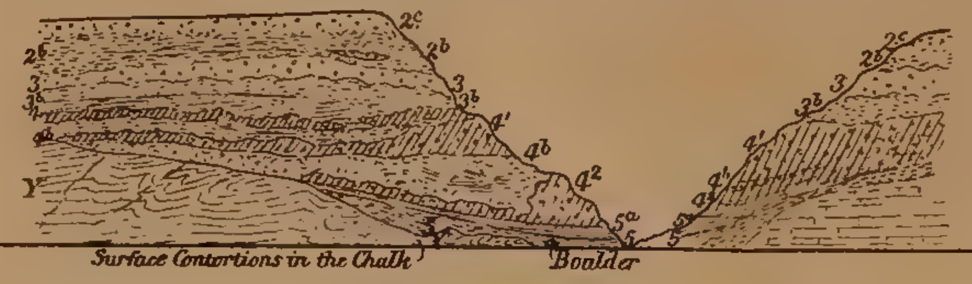



Fig. 6. Cliff-Section at Beacon Hill.

Showing sudden thickening of the Intermediate Stratified Series


Fig. 7. Cliff-Section on West Side of South Sea Landing.

Showing edge of Chalk hollow, with drift beds below Basement Clay.


## Explanation of Figs. 2 to 13.

1. Post glacial Alluvial Beds.

2b. The Sewerby Gravels.

2c. (Fig. 5 only) Stony earth, like weathered Boulder Clay.

3. Upper Boulder Clay of Flamborough Head. 3x ("Hessle" Clay?), 3a ("Upper Purple" Clay), 3c ("Lower Purple" Clay), of Figs. 2 & 3 separate bands of Boulder Clay, comparable to those of Holderness.

3b. Intermediate Series of Flamborough Head. (In Figs. 2 & 3 this number is applied to the Stratified Beds between the "Purple" Clays) 3b' (Fig. 8) Chalky Morainic Gravel. 3b'' (Fig. 8) Gravel without Chalk. 3b'' Boulder Clay of the Intermediate Series.

4. Basement Boulder Clay. 4¹ (Figs. 9 & 10) Upper Shelly layer. 4² Layer composed chiefly of Speeton Clay. 4³ Layer composed chiefly of crushed chalk. 4a (of Fig. 3.) Laminated Clay of Bridlington. 4b (of Fig. 5) Morainic Gravels; connected with the Basement Clay.

5. Chalky Rubble. 5a Silty Beds. (in Fig. 5.), or sand, silt and fine gravel, (in Fig. 7); 5b (in Fig. 7) Rough unfossiliferous drift-gravel resting on chalk.

A.B.C. (Fig. 4.) Buried Cliff Beds of Sewerby (fossiliferous) A. Old Beach. B. Land Wash. C. Blown sand.

A. (Fig. 13.) Speeton Estuarine Shell-bed; with (A') thin bed of local gravel at base.

Y. White Chalk.

Z. Speeton Clay.

Note. The beds bearing the same number in the different Sections are not necessarily conterminous.

## Sections on the North Side of Flamborough Head.

Fig. 8. Cliff-Section on the North Side of High Stacks Blow-hole.

Showing infilling of buried Ravine.


Fig. 9. Cliff-Section at Stottle Bank

Showing lower bands of Basement Clay thinning out against chalk slope.

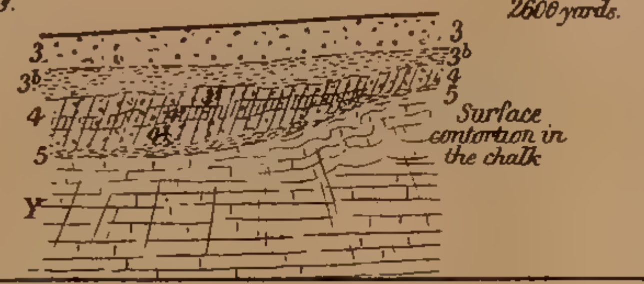



Fig. 10. Cliff-Section at Sanwick.

Through the edge of a gravel mound.

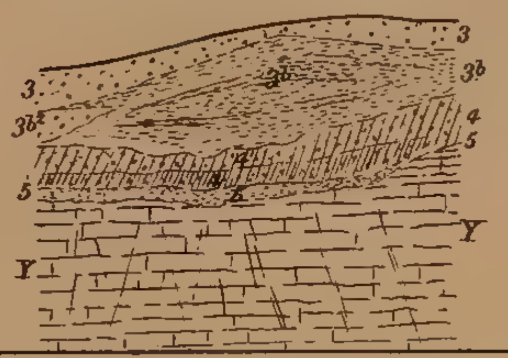



Fig. 11. Cliff-Section near Old Roll up, Bempton.

Where the Drift is thin.


Fig. 12. Cliff-Section near Matthew Allison Nab, Buckton.

through a gravel mound.

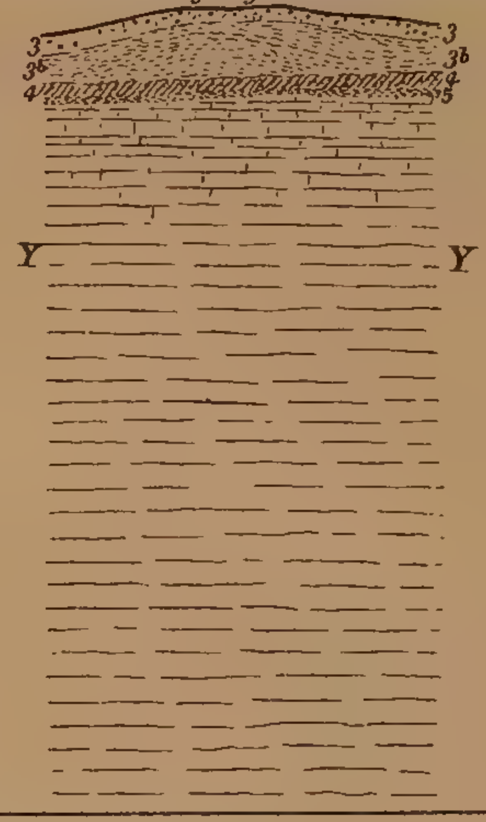



Fig. 13. Section on Middle Cliff Ridge, Speeton.

Showing Estuarine Shell-bed below the drifts.

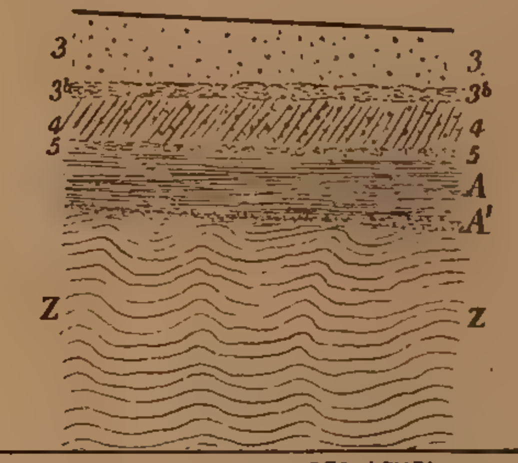
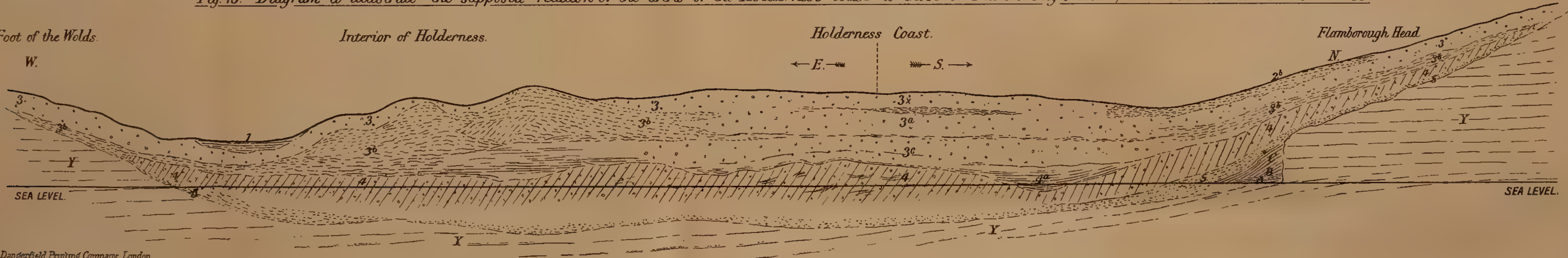



Fig. 15. Diagram to illustrate the supposed relation of the drifts of the Holderness Coast to those of Flamborough Head, and of the interior of Holderness.




### Explanation of Diagram Fig 15.

1. Post-glacial & Alluvial beds.

2b. Sewerby Gravel.

3x. Hessle Clay of Holderness. } 3 Upper Clay of Flambro' and Interior

3a. Upper Purple Clay of Holderness.

3c. Lower Purple Clay of Holderness. } 3b Intermediate Stratified Series of Flambro' and Interior.

4a. Laminated Clay of Bridlington passing upwards into 3c and downwards into 4.

4. Basement Clay.

5. Chalk Rubble.

A.B.C. Buried Cliff Beds.

Y. Chalk.

(Length from either end to the centre-point of the Diagram, about eight miles.)

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which Mr. Reid had raised, as they had on these points always held different views. He believed that this was chiefly because Mr. Reid had worked northwards from the Humber, while the Author had worked southwards from Flamborough.

On Flamborough Head the Intermediate beds could not be marine, but the sea may possibly have been present in some part of the Holderness recess during their deposition, though the evidence for this was by no means convincing, and part, at any rate, of the fauna could scarcely be contemporaneous. If the Holderness "inter-Glacial" deposits were older than the Basement Clay, as Mr. Reid supposed, it was curious that they should have retained their mound-like features during the extended glaciation which followed.

He thought it was unsafe to rest any conclusions on the dip of the deposits in this area, as they were evidently moulded upon a pre-Glacial surface, and were, besides, in every way irregular.

The mounds had much in common with eskers, but their direction and their position near the edge of the glaciated area could not be explained on the commonly-accepted esker-theory. It was difficult to say how to define the term "esker," and when to apply it.

He admitted the glacial character of the mammalian fauna of the Buried-Cliff beds, but thought that this was what we might expect to find below the Boulder-clays in an area so far removed from the centres of glaciation.

The Buried Cliff had been preserved from subaerial degradation by the blown sand which was banked against it.

## 24. *On the* Igneous Rocks *of the* South *of the* Isle *of* Man.

By Bernard Hobson, Esq., M.Sc., F.G.S., Assistant Lecturer in Geology at the Owens College, Manchester. (Read April 8, 1891.)

[Plate XIV.]

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### I. Previous Literature.

Though the igneous rocks of the Isle of Man have been cursorily described by Berger *, Henslow †, and Macculloch ‡, the most satisfactory account of them is contained in the work of the Rev. J. G. Cumming § and in the paper by Mr. Horne ‖. The Rev. J. Clifton Ward ¶ has also given an interesting sketch of their geology.

In the "Journal of the Liverpool Geological Association," vol. ix. (1888–89) pp. 41–47, is a paper entitled "Notes on some Manx Lavas," by Isaac E. George, but it hardly contains much information.

In the "Proceedings of the Liverpool Geological Society," vol. vi. pt. i. (1888–9) pp. 123–131, is a paper on "An Examination of some Volcanic Rocks of the Isle of Man," ** by Messrs. Dickson and Holland, containing analyses of 5 specimens, and a description by Mr. Rutley of 10 specimens.

### II. Main Features of the Geology of the District.

The greater part of the Isle of Man consists of slates, which are usually held to be of Lower Silurian age, but in the south of the island Carboniferous rocks occur. They occupy an area of about 7 square miles and overlie the slates unconformably, extending from Cass-ny-Hawin on the east coast to near Athol Bridge over the

* Trans. Geol. Soc. vol. ii. (1814) pp. 29–65.
† *Ibid.* vol. v. (1821) pp. 482–505 and pl. xxxv.
‡ 'Western Islands of Scotland' (1819), vol. ii. p. 571, and vol. iii. pl. xxvii.
§ 'The Isle of Man' (with 8 pls. and 10 views), London (1848).
‖ Trans. Edin. Geol. Soc. vol. ii. (1874) pp. 323–347.
¶ Geol. Mag. (1880) p. 5.
** The writer was unacquainted with this paper at the time of reading the present one, so that all references to it have been added since. (June, 1891.)

Silverburn on the north-west, thence, bounded on the west by a fault which throws them down against the slates, to Strandhall. Bounded on the south by the sea, they extend eastwards from Strandhall to the peninsula of Langness, where they are thrown down against the slates by two faults. From Langness northward they are bounded by the sea. They consist, in descending order, of:—

4. Poolvash black marble beds (with interbedded volcanic tuff) = Posidonian schist of Cumming.
3. Upper or Poolvash limestone.
2. Lower or Castletown limestone.
1. Conglomerate and sandstone.

Numbers 2 to 4 belong to the Carboniferous Limestone series. No. 1 was held by Cumming to be of Old Red Sandstone age, but is more probably of Calciferous Sandstone age, as shown by Horne *.

## III. Types of Igneous Rocks met with.

Omitting from consideration the granite which occurs at Foxdale, as well as north of Laxey, we have evidence of at least five and possibly six distinct series of volcanic rocks differing both in composition and in age. The earliest series is:

(a) *The Diabase Series.*—This is best seen in the peninsula of Langness, and is termed by Cumming "greenstone." It is certainly of pre-Carboniferous age, as it never penetrates the basal Carboniferous conglomerate. It forms dykes and intrusive masses in the Silurian slates and often follows closely their line of strike, so that its intrusive character is not obvious at the first glance. The general direction of strike is north-easterly, being thus quite different from that of the olivine-dolerite dykes, which is north-westerly. I have not worked out the details of the diabase dykes, &c.

(b) *The Micro-granite Dyke.*—On the hillside S. 41° W.† of Crosby railway-station a micro-granite dyke 24 feet wide cuts through the Silurian slates with a northerly strike, and is exposed in two small quarries worked for road-metal. The slates have been altered at the point of contact into a micaceous schist. The interesting feature of this dyke is the parallel structure of its salbands. According to Prof. Boyd Dawkins's manuscript notes and map, the general direction of strike of this dyke is north-easterly, and it can be traced south-westward by St. Runn's Church and St. Patrick's Chair to Windy Common.

(c) *The Augite-porphyrite Series.*—This is exposed in a narrow strip a mile and a quarter long, extending from Scarlet Point, south-west of Castletown, in a north-westerly direction to Poyll Vaaish (Poolvash). It consists of tuff, breccia, agglomerate, bedded lava, and intrusive masses, the whole forming "a small ancient volcano, dissected and laid bare," to quote the Rev. J. C. Ward ‡. Some of

* Trans. Edin. Geol. Soc. vol. ii. (1874) p. 327.
† All compass bearings are corrected 21° west for magnetic declination.
‡ Geol. Mag. (1880) p. 5.

the tuff can be shown to be of the age of the Carboniferous Poolvash black marble, which is regarded by Mr. R. Etheridge, jun., as probably referable to the horizon of the Upper Limestone shales *. The whole of the augite-porphyrite series probably belongs to the same period, as will be shown subsequently.

(d) *The Melaphyre Dyke.*—This dyke intervenes between the Lower Limestones and the augite-porphyrite agglomerate at Scarlet Point, and strikes N. 61° W., apparently occupying a line of fault.

It resembles the augite-porphyrites in microscopic structure, the only important difference being the occurrence in it of porphyritic augite †. Its specific gravity, 2·77 to 2·81, agrees very fairly with that of the augite-porphyrite of the Stack [522], which is 2·78. Hence I regard it as a final product of the series of augite-porphyrite eruptions, and therefore as probably of Lower Carboniferous age.

(e) *The Picrite-porphyrite.*—This occurs in the village of Poortown, near Rockmount, north-west of St. Johns. It is quarried for road-metal. Cumming terms this variously "hornblende-rock" (he has probably mistaken the augite for hornblende) and "porphyry." He states that the same rock occurs at Cronk Urley and at Port St. Mary, and regards it as post-Carboniferous in age, "for it appears to have tilted . . the old red sandstone [Carboniferous] . . . . to a high angle" ‡, and the same rock is "developed almost continuously along the fault . . . . running from Perwick Bay through Port St. Mary, Strandhall, and Athol Bridge . . . . . . cutting off at once all the carboniferous series to the N.W. of this line." Henslow § also mentions this rock as occurring at Port St. Mary in these words: "A bed of greenstone, in which the hornblende is remarkably well crystallized, occurs to the south of Port le Murray . . . . forming a ridge eight or ten feet broad." Although I have not seen this dyke I believe Berger and Cumming to be quite correct, for in September 1887 I observed on the shore on the inner side of the pier a large block of dark green rock with the drill-holes in it, evidently blasted in making the new pier at Port St. Mary, and it agrees with the Poortown rock, when examined microscopically, in containing similar porphyritic augite-crystals, though they are rather less plentiful. Probably the pier is built upon the dyke.

(f) *The Olivine-dolerite Series.*—This is exposed in the form of dykes between tide-marks on the east shore of Bay-ny-Carrickey from Kentraugh to Scarlet Point; on both the west and the east shores of Castletown Bay, and also on the east side of Langness; at Derbyhaven breakwater and between Ronaldsway and Cass-ny-Hawin. These dykes are from 8 inches or less to 30 feet wide, and the average strike calculated from 36 observations is N. 44° W. With one exception striking N. 26° E., the strike of them all is comprised

* Etheridge in Horne's paper, Trans. Edin. Geol. Soc. vol. ii. (1874) p. 331.

† Throughout this paper I use the term 'porphyritic' in the sense of Rosenbusch, 'Mikr. Physiogr. d. massig. Gest.' (1887) pp. 339, 340, *i. e.* irrespective of size, for the first (intratelluric) generation of crystals in a rock in which there has been recurrence of phase.

‡ 'Isle of Man,' pp. 194, 245, and note on p. 239.

§ Trans. Geol. Soc. vol. v. (1821) p. 497.

in the quadrant between N. and W. As they cut through all the beds up to and including the Poolvash black marble and associated tuff they must be newer than those beds, and Mr. Horne * suggests that they may be of Miocene age. The only evidence in favour of their early Tertiary age is the fact that they agree with known Tertiary basaltic rocks of the North of Ireland and the West of Scotland, in being ophitic olivine-dolerites (or basalts) and in their prevalent north-westerly strike †. They are quite distinct from the augite-porphyrite series as Mr. Horne points out ‡, though Cumming was inclined to regard them as accompaniments of it §. They usually weather to a dark olive-green colour, and weathering generally takes place more rapidly in their case than in that of the "country" rock, giving rise to long channel-like depressions, which are often indicated on the six-inch map.

## IV. Detailed Description of the Geology of Scarlet Point, &c.

The numbers in the following description refer to the localities marked on the map of Scarlet Point (Pl. XIV.).

Starting at Castletown, let us follow the western shore of Castletown Bay southwards towards Scarlet Point.

About 180 yards S.W. of the Scarlet limestone quarry we come upon a small syncline in the limestone. Running along the bottom of this syncline is a dyke [523] 5 feet wide ‖. From 30 to 70 yards south-west of this dyke we come upon a shingle-covered gap in the limestone, 79 feet broad, in which the following occur:—

| | Feet. | Reference Number. |
|---|---|---|
| Branching olivine-dolerite dyke or dykes with included limestone-patches | 28 | 31 |
| Shingle, &c. (see below) | 13 | |
| Black limestone | 5 | |
| Augite-porphyrite dyke (?) | 15 | 32 |
| Augite-porphyrite breccia | 18 | 33 |
| Total | 79 | |

With regard to the 13 feet of "shingle, &c.," the south-western 7 feet are augite-porphyrite, perhaps not *in situ*; but I believe the greater part of the 13 feet to be occupied by the "melaphyre dyke" [501] previously referred to (p. 434), for the following reasons:—At a point 17 feet to the south of the "Spring" on the map there is a small exposure of that dyke. The dyke can be traced for 180 feet, and appears to occupy the line of a fault by which the volcanic rocks have been thrown down on the south

* Trans. Edin. Geol. Soc. vol. ii. (1874) p. 336.

† A. Geikie, 'History of Volcanic action during the Tertiary Period, &c.,' Trans. Roy. Soc. Edin. 1888 (reprint), p. 30; but see also Judd, Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 209.

‡ Trans. Edin. Geol. Soc. vol. ii. (1874) p. 332.

§ 'Isle of Man,' p. 244.

‖ See Cumming's 'Isle of Man,' p. 122.

against the limestone. If the line of strike of the dyke be produced, it will fall within the broad gap above described. Having failed to find the rock there *in situ*, I searched for blocks of it and found one there near low-water mark measuring 4 ft. × $3\frac{1}{2}$ ft. × 3 ft. This renders it almost certain that the dyke occurs in the gap.

On the south-western side of the gap is a large patch of limestone, the lower beds of which Cumming considers to belong to the Lower Limestone series which occurs to the north of the gap, while the upper portion of it is held by him to belong to the Poolvash limestone *. To the south the patch of limestone is cut off by a wall-like dyke [517] of augite-porphyrite. This dyke is probably continuous with the great dyke [500 A] to be subsequently described. On the south-western side of the dyke [517] is a portion [528] of the Lower Limestone with shaly layers violently contorted, being thrown into an anticlinal curve and tilted so that the crown of the arch dips at 17° to N. 66° W. Cumming represents this in his section (*loc. cit.*) as being *in situ*, but it appears to be borne on the back of a mass of augite-porphyrite (perhaps part of the same mass as 517) which is exposed, at low water only, to the east of it, with the denuded sides of the limestone arch still overlying its margins. Abutting against the western margin of this small contorted limestone-patch is augite-porphyrite, forming part of a very large intrusive mass which terminates southward in the Stack of Scarlet and extends nearly 200 yards north-westwards.

The Stack of Scarlet is a somewhat precipitous, dark-coloured, obtusely conical mass, rising 50 feet above low-water mark. It is an island at high tide. The rock of the Stack is more or less distinctly columnar. The columns are from 15 to 18 inches across and nearly vertical. Some evidence of the age of the Stack is afforded by the fact that on the south-west side a band of black limestone about 2 inches broad is entangled between the columns. Between the limestone patch [528] and the Stack are three other small masses of black limestone embedded in the augite-porphyrite or agglomerate. The intrusive mass forming the Stack appears to be continued northwards to form a low isthmus, and then rises into a great wall-like ridge [500 A] some 40 feet across. Here it has all the characters of an intrusive dyke. Its sides are vertical and at high tide it forms a promontory. It can be traced north-westwards "to the point where an isolated patch of porphyrite rests on the ash" †. Whether it can be traced beyond the "isolated patch" is uncertain, but it is perhaps continuous with a broad band of augite-porphyrite which extends from near that point, protruding but slightly above the grass towards a mass [503] which has almost the appearance of a bedded lava-sheet rather than that of an intrusive dyke.

The space between the dyke [500 A] and the sea on its south-west side is occupied by agglomerate, which can be seen at low water to overlie greenish volcanic tuff. Similar agglomerate covers the space

* 'Isle of Man,' pl. vii. fig. 5.

† Horne, Trans. Edin. Geol. Soc. vol. ii. (1874) p. 335.

to the north of the dyke right up to the line of fault and melaphyre dyke [501]. This agglomerate consists chiefly of more or less rounded blocks of augite-porphyrite three or four inches in diameter (though larger blocks occur) embedded in a matrix of finer volcanic tuff. Overlying this agglomerate to the north of the dyke [500 A] are several fragmentary patches of bedded augite-porphyrite lava, *e. g.* nos. 155 and 157.

Within five feet to N. of the dyke [500 A] a mass of lava and agglomerate 63 feet long × 26 feet broad (exposed) is tilted so as to dip at 45° to S. 19° W. Several other masses of augite-porphyrite occur, of which it is often difficult to say whether they are to be regarded as tilted lava-beds or intrusive dykes.

At the spot marked 524 the geology is rather puzzling. The agglomerate surrounding the dyke [500 A] abuts against a higher, slightly overhanging, greenish mass, which appears under the microscope to consist of very minutely amygdaloidal augite-porphyrite fragments with a calcareous cement. Perhaps we have here a faulted junction. To the west of 524 a deep cleft has been worn by the sea, and a few yards west of the cleft lava is seen overlying agglomerate and overlooking a second much longer, but shallower, narrow inlet. It appears to me probable that a fault runs along this inlet, for on the eastern side of it we have very distinct agglomerate, which does not appear to be present at all on the western side. If there be a fault the downthrow is probably on the west, for a bed of augite-porphyrite [171], 3 feet thick, on the western side of the inlet, is tilted so as to dip at 22° to N. 71° W.

Tuff overlies the bed of lava just mentioned, and extends for not less than 100 yards westwards to a point where it is cut off by a fault striking N. 53° W. The line of fault is excellently exposed, the fine tuff devoid of blocks being brought into immediate contact with a coarse agglomerate, both being bare of vegetation, so that the boundary between them is as sharply defined as it is possible to imagine. I believe the tuff to be on the downthrow side, although on examining it towards the top of the exposure, near the margin of the grass below the footpath, a few blocks of lava hardly as large as a man's head may be seen, which may be an indication of the coming on of the base of the agglomerate. The agglomerate forms a strip bounded on the north-east by the fault just described and on the south-west by another parallel fault, the evidence for which is as follows:—A bed [174] of reddish-looking augite-porphyrite lava 15 feet thick, in places nearly vertical, in others dipping at 60° to W. 53° S., rises like a wall to a height of 40 feet above the triangular patch of agglomerate at its south-western base and can be traced inland to the ruined shed 17 yards to S.W. of the "Remains of Burial Ground"*. The present position of this lava-bed is evidently due to a fault striking N. 53° W., as described (with section) by Mr. Horne †. The downthrow of the fault is on the south-west. On the north-east, at a distance of 10 yards, a portion [525] of the same bed in its

* See six-inch map, sheet 16.

† Trans. Edin. Geol. Soc. vol. ii. (1874) p. 334.

normal horizontal position overlies the agglomerate. A few yards to the N.W. of the mass 525, where the lava-sheet is much disturbed, a small mass of lava is overlain by agglomerate ; but this is perhaps due to inversion, as it seems to be the rule that lava overlies agglomerate.

On the north-eastern side of the great tilted bed, where the lava has been removed by denudation, we have the underlying agglomerate exposed. It is very coarse and contains blocks of augite-porphyrite as much as 4 × 3 feet and of black Poolvash marble, one of which measures 4 × $1\frac{1}{3}$ × 2 feet.

Large patches of limestone, apparently belonging to the Poolvash marble, occur in the agglomerate here. One measures 20 × 9 × 4 feet, and another near low-water mark 53 × 24 feet. Whether they have been deposited *in situ* or not is hard to say, they are so involved in the agglomerate.

About 320 yards to the west of the great tilted lava-bed and S.S.E. of the "Remains of Burial Ground" before mentioned, a bed of augite-porphyrite dipping at from 30° to 40° to N. 84° E., and varying from 1 foot 3 inches at its landward end to 7 feet in thickness seawards, may be observed in the tuff. This bed, like that [174] previously mentioned, owes its present position to a fault striking in this case N. 6° W.

Proceeding northward along the east coast of Bay-ny-Carrickey we observe the volcanic tuff and the black Poolvash marble interstratified. This is particularly well seen to south of Close-ny-Chollagh Point, opposite the "H" of "High Water Mark," on the six-inch map (sheet 16) *. This shows that the tuff is at least in part of Lower-Carboniferous age, and since the dip of the tuff where it can be observed is usually westerly, we may conclude that the augite-porphyrite dykes and lava-beds at Scarlet are not newer, but probably belong to the same period.

A dyke, apparently belonging to the augite-porphyrite series, occurs at Langness. The locality is near "The Arches" in the little cove immediately to north of the most northerly natural arch. The dyke is 3 feet wide, strikes N. 60° E., and cuts through both the Silurian slates and two isolated patches of the Carboniferous conglomerate. The rock is marked by numerous bands of amygdules showing fluxion-structure. Under the microscope it is seen to be full of minute felspar-laths and larger, perhaps porphyritic, felspars, while porphyritic pseudomorphs, probably after olivine, are embedded in a base darkened by abundant iron-ore.

## V. Macroscopical and Microscopical Characters of the Rocks.

(a) *The Diabase Series.*—Not having worked out this series in detail, I confine myself to describing a single specimen, No. 521. My specimen is from Gullet Buigh, on the east coast of Langness. The same mass appears to extend for many yards in the direction N. 44° E., and is probably a dyke.

The rock somewhat resembles the greenstones at Mynydd Gader,

* See also Horne, Trans. Edin. Geol. Soc. vol. ii. (1874) p. 333.

on the north slope of Cader Idris, in macroscopical appearance. It is a green, distinctly crystalline rock with specks of iron-pyrites. Sp. grav. 2·87.

As regards its microscopic characters *, I may mention that large idiomorphic crystals of colourless (?) augite †, mostly altered to brownish decomposition-products, are accompanied by a small quantity of partially idiomorphic hornblende, brown by transmitted light, and cloudy altered felspar containing apatite needles. The space between the felspars is occupied by chlorite, calcite, and other alteration-products. Small patches of leucoxene occur, and the rock as a whole is *much altered.*

(b) *The Micro-granite Dyke.*—Specimen 204 from centre of dyke. A greyish fine-grained rock (coarse-grained for a micro-granite) in which white mica in small hexagonal plates is more conspicuous than dark mica ; with care porphyritic felspar-crystals can be made out, and the bulk of the rock is seen, on examination with a lens, to consist of felspar and quartz. No parallel structure is visible. The specific gravity of the rock is 2·62.

Specimen 205 A, from about 6 inches from the western salband of the dyke. In this a very distinct parallel structure or foliation is developed, the foliation planes being parallel to the edge of the dyke.

The hexagonal plates of white mica are larger and more conspicuous than in 204, and have often their basal pinacoid faces lying quite obliquely to the foliation planes, the direction of which is indicated by fine dark subparallel lines traversing the *compact* light grey groundmass, in which, by careful examination with a lens, small porphyritic quartz-crystals can be made out.

The following chemical analysis of a specimen of the Crosby dyke close to the contact is given by Messrs. Dickson and Holland ‡ :—

| | |
|---|---|
| $SiO_2$ | 74·39 |
| $Al_2O_3$ | 15·55 |
| $Fe_2O_3$ | 1·35 |
| MnO | 0·22 |
| CaO | 0·48 |
| MgO | 0·33 |
| $K_2O$ | 2·14 |
| $Na_2O$ | 3·79 |
| Combined Water | 1·18 |
| | 99·43 |

Sp. grav. 2·72 (?). A specimen lent to me by Mr. Dickson gave 2·62.

The rock is therefore a micro-granitic keratophyre (soda-felsite). If the whole of the potash be calculated as orthoclase from the

* Compare remarks on sect. 250 among Supplementary Observations.

† If it were not for the high extinction-angle (about 40°), I should be disposed to regard this as epidote pseudomorphous after hornblende.

‡ Proc. L'pool Geol. Soc. vol. vi. pt. i. (1889) p. 126. Compare the analyses (and descriptions) of soda-felsites from Co. Wicklow in Dr. Hatch's paper, Geol. Mag. (1889) p. 546.

formula $K_2O\ Al_2O_3\ (SiO_2)_6$, and the soda as albite from the formula $Na_2O\ Al_2O_3\ (SiO_2)_6$, the following percentages are obtained:—

| | |
|---|---|
| Orthoclase percentage ........ | 12·6 |
| Albite percentage ............ | 32·0 |

A section cut for the microscope from spec. 204 (centre of dyke) consists of quartz, orthoclase, plagioclase, a microcline-like felspar, white mica and dark mica. The bulk of the rock consists of a granular aggregate of quartz, felspar, and mica, the average diameter of the constituents being 0·2 millim. White mica is much more abundant than dark mica. Larger, apparently porphyritic crystals of plagioclase, microcline-like felspar, and white mica occur. The porphyritic felspars are sometimes bounded by crystal faces, but their boundaries are usually irregular. They are generally cloudy and contain abundant flakes of white mica. The irregular boundaries of the large crystals are probably due to dynamic metamorphism, as undulose extinction is frequent. No parallel structure is visible.

In a section cut at right angles to foliation from specimen 205 A (about 6 inches from the western edge of the dyke), we see that the greater part of the rock consists of a mosaic of much smaller grains than in 204 (average diameter 0·07 millim.). In this mosaic large aggregates consisting partly of cloudy, often multiple-twinned, and partly of water-clear, not visibly twinned felspar (the latter free from minute inclusions, but containing large lath-shaped sections of white mica) stand out like porphyritic constituents and often exhibit undulose extinction. Solitary large lath-shaped sections of white mica also occur, and are sometimes bent so that one end extinguishes completely while the remainder shows brilliant interference-colours. Apatite occurs in the felspar of this section and Nos. 204 & 205.

If the section be examined by ordinary light with a low power (2-inch) it will be seen to be traversed by irregular subparallel narrow dark lines looking almost like cracks. If these darker lines be examined with a high power ($\frac{1}{4}$ inch) they will be seen to be due to bands of minute black particles (magnetite?) *, and it will be observed that each band is accompanied by the development of white mica †, which, though not confined to the dark bands, is much more abundant there than elsewhere.

Section 205, from the east side of the dyke, shows the contact between the dyke and the slates. The micro-granite is very fine-grained; the average diameter of the constituents is about ·05 millim. White or slightly greenish mica is very abundant in laths ·05 millim. long. Close to the junction with the schist brown mica due to contact is developed. These smaller constituents show a marked tendency to arrange themselves parallel to the line of contact.

* A similar arrangement of magnetite grains in an altered slate is figured and described by Allport in Quart. Journ. Geol. Soc. vol. xxxii. (1876) p. 410, and pl. xxiii. fig. 6.

† Compare Rosenbusch's description of "Quetschzonen," 'Mikr. Physiogr. d. massig. Gest.' (1887) pp. 439, 440.

The porphyritic constituents resemble those of 205 A, but quartz was also observed. They vary in diameter from ·37 millim. to 1·57 millim. The boundary between the dyke and the micaceous schist is perfectly sharply defined, though small intrusive tongues of micro-granite penetrate the schist. In the schist the brown mica is arranged at quite oblique angles to the foliation planes. This is seen even in the hand-specimen.

I hesitate as to whether I should ascribe the foliation of the salbands of this dyke to dynamic metamorphism, but am inclined to do so.

(c) *The Augite-porphyrite Series.*—In the following description the numbers refer to the localities on the map of Scarlet Point (Pl. XIV.).

The macroscopic characters differ somewhat according to the more or less completely crystalline state of the rock. The rock of the Stack [522] is most crystalline, and is of a grey colour with a tinge of green. Porphyritic plagioclase-crystals, as much as $\frac{1}{4}$ inch long, are embedded in a groundmass of which the constituents are not determinable macroscopically. A specimen of 500 A is similar, except that the groundmass is more completely compact, and rarely pseudomorphs after porphyritic olivine occur. In the breccia [200] and similar very amygdaloidal and less crystalline specimens, no porphyritic plagioclase can be made out, and the rock often looks very like a piece of light-coloured Carboniferous limestone.

All these rocks weather reddish-brown at the surface where not exposed to the sea, but dark brown where exposed to it at the Stack, &c. Where weathering has removed the amygdules they are often vesicular. Internally the weathered parts are greenish.

Messrs. Dickson and Holland * give the analysis of a specimen from the summit of Scarlet Stack, showing a silica percentage of 46·70. The specific gravity, 2·62, quoted for the specimen is incorrect; I have redetermined it from Mr. Dickson's specimen to be 2·76. The average specific gravity of the augite-porphyrite is as follows:—

Specific gravity of

| | |
|---|---|
| No. 156 = 2·75 | 155 = 2·76 |
| „ 500 A = 2·75 | 522 = 2·78. |

Average specific gravity 2·76.

I will now describe a section cut for the microscope from the lava-bed [155], which I submitted to Prof. Rosenbusch, who pronounced it to be an augite-porphyrite allied to the spilite † type.

The structure is distinctly porphyritic, the porphyritic constituents being large idiomorphic plagioclase-crystals. The groundmass consists of much smaller lath-shaped plagioclase-crystals, black iron-ore, chlorite, titanite, and some calcareous alteration-products.

The porphyritic plagioclase-crystals are of large size and distinctly idiomorphic. One of average size measured 2·81 millim. × ·71 millim. Mostly polysynthetic twins, some of them show twinning on the

* Proc. L'pool Geol. Soc. vol. vi. pt. i. (1889) p. 128.

† Rosenbusch, 'Mikr. Physiogr. d. massig. Gest.' (1887) p. 493.

albite combined with the pericline plan; their margins, in some cases uncorroded, are in others considerably corroded by the groundmass. While some are moderately fresh, others are much altered, the alteration proceeding from the margin inwards until either only a small irregular central patch is left or the whole is altered. The altered portions consist, to the extent of about half, of felspar and about the same quantity of chlorite, which forms irregular patches. The alteration is perhaps partly due to the felspar having been originally honeycombed by the interstitial matter of the groundmass, as occurs in sections 172 (ejected block), 156, &c.

Fluxion-structure is very evident in the groundmass, which consists largely of plagioclase lath-shaped in section. An individual slightly above the average size measured ·36 millim. × ·055 millim.

The space between the plagioclase crystals of the groundmass is occupied by chlorite and minute grains of iron ore, probably altered ilmenite. Larger patches of iron ore, often showing crystalline form and aggregates ·73 millim. in diameter and more, occur. Most of the iron ore appears opaque-white by reflected light, and is therefore changed to leucoxene. In other parts the change has proceeded so far as to form perfectly distinct crystalline aggregates of titanite (sphene). Augite is not present in any of the specimens of augite-porphyrite. Its original presence is inferred from the occurrence of chlorite, and the structure of the rock also from its basic nature, as shown by analysis and indicated by the presence of pseudomorphs after olivine in some specimens.

Section 155 may be considered an average specimen of augite-porphyrite. Sections 156, 171, 172, 174, 503, 517, and 500 A′ (fine-grained specimen from south-west side of dyke 500 A), agree with it in most respects, but porphyritic plagioclase is sometimes absent, and No. 156 is very amygdaloidal. Pseudomorphs (consisting of carbonates and serpentine) after large idiomorphic porphyritic olivine occur in 500 A′ (and 500 A), 517, and, according to Mr. Rutley *, in the rock of Scarlet Stack. Mr. Rutley mentions rhombic pyroxene as occurring in the dyke leading from Scarlet Stack to the mainland (my 500 A). Section 500 A is considerably coarser-grained than 155, and sect. 522, from Scarlet Stack, is the most coarsely crystalline of all, the average size of the felspars of the groundmass being ·75 millim. × ·10 millim., and fluxion-structure being far less marked than in No. 155. The porphyritic plagioclase occasionally shows zone-structure. Chalcedony occurs as an alteration-product.

Section 500. Volcanic tuff from Scarlet Point; this is a soft yellowish-green bedded tuff.

Microscopical characters: it contains irregular fragments of the following types, all of which seem to be simply one and the same augite-porphyrite magma solidified under varying conditions:—

A. Pumiceous fragments crowded with vesicles which occupy more space than the solid part. The vesicles are drawn out longitudinally, indicating flow when in a viscid state, and are occupied

* Quoted in Messrs. Dickson and Holland's paper, Proc. L'pool Geol. Soc. vol. vi. pt. i. (1889) pp. 128 and 130.

by chlorite and sometimes calcite. The originally vitreous material forming their walls contains abundant grains of leucoxene.

B. Fragments almost as full of vesicles as A, but in which the glass is rendered brown by very fine dust-like inclusions. Larger acicular dark-coloured rods, white by reflected light, probably leucoxene, are abundant, and occasionally a lath-shaped plagioclase crystal may be seen.

C. Scoriaceous fragments in which the vesicles and the solid part occupy about equal space. In these fragments the vesicles vary greatly in size from less than ·05 to 2·87 millim. in diameter, whereas in A and B they are fairly uniform in size, and about ·1 millim. in longer diameter *. The cavities of the scoriaceous fragments are occupied in most cases by chlorite, in some cases by chlorite and calcite. The solid part contains very small lath-shaped plagioclase and abundant iron-ore. None of it is isotropic; probably this is due to secondary alteration.

The fragment of type C appears to be part of a small ejected block rather than a normal integral part of the tuff.

The fragments are cemented by a calcareous cement. Specimens 33 and 200 differ considerably from 500 in macroscopical appearance, being hard breccias in which greenish fragments of augite-porphyrite, sometimes as much as an inch across, are embedded in a grey calcareous matrix. Microscopically they are seen to consist chiefly of scoriaceous fragments of the type C just described. Idiomorphic crystals of iron-pyrites are present in the amygdules of 200.

Sections 160 and 502 A (both from ejected blocks in the agglomerate) agree with type C of section 500 in structure, but the amygdaloidal cavities are smaller and much more crowded, and the felspar laths more abundant. In section 160 pseudomorphs after porphyritic olivine are present, and the rock is seen to consist of a breccia in which fragments of a previously-solidified very vesicular lava are embedded in similar lava with evident fluxion-structure, the slender felspars being arranged parallel to the contours of the included fragments †.

(d) *The Melaphyre Dyke.*—Large plagioclase- and augite-crystals and pseudomorphs after olivine are embedded in a compact grey groundmass. The specific gravity of three specimens was respectively 2·77, 2·78, 2·81; average 2·79 (the specimens were not free from amygdules).

Sections 501 and 501 B ‡, cut for the microscope, show large idiomorphic porphyritic crystals of plagioclase. In some of the plagioclase crystals the twinning lamellæ terminate abruptly at cracks, or are only faintly indicated at the other side of cracks in the crystal. In these crystals undulose extinction was observed. We may therefore consider the twinning in these cases to be due to pressure §. The crystals are in some cases eroded by the groundmass,

* In A much larger vesicles do occur.

† Compare Fouqué and Lévy, 'Minéral. micrbelievegr.' (1879) pl. xxxii.

‡ Loose block on shore, see *ante*.

§ See Judd, Quart. Journ. Geol. Soc. vol. xli. (1885) p. 366; Förstner, Zeitschr für Krystallogr. vol. ix. (1884) p. 333.

and in one case enclosed a pseudomorph after an olivine crystal. The porphyritic plagioclase is, as a rule, remarkably fresh.

These sections also contain large idiomorphic porphyritic augite crystals of violet-brown colour by transmitted light; and pseudomorphs after idiomorphic porphyritic olivine. The last-named consist chiefly of calcite traversed by irregular bands of serpentine which has been formed along cracks in the original crystal.

In the groundmass magnetite or ilmenite occurs in two forms:—1st. As small, apparently idiomorphic crystals (probably original constituents), in abundance; 2nd. As large irregular patches with ragged margins. These patches are in places altered to opaque-whitish leucoxene, and are perhaps secondary. The chief constituent of the groundmass is plagioclase in small crystals of short lath-shaped section. Augite, often in idiomorphic crystals, occupies the spaces between the felspar crystals, but is mostly altered to chlorite and a dirty brownish granular decomposition-product.

There are large amygdules in the rock, which consist chiefly of radiating fibrous greenish material.

The rock, both in the hand-specimen and under the microscope, bears a considerable resemblance to the well-known porphyritic olivine-basalt of the Lion's Haunch, Arthur's Seat, Edinburgh *, the most obvious difference being the predominating lath-shape of the felspars of the groundmass in the Manx rock. This resemblance is a point of considerable interest, since Prof. Judd has shown † that the volcanic rocks of Arthur's Seat are probably of Lower-Carboniferous age; and Prof. Hull has described ‡ a "porphyritic melaphyre" bearing "a close resemblance to the rock from the Lion's Haunch" as occurring at Ballytrasna, and belonging to the "Upper Trap-band" a little below the basal shales of the Coal-measures. As it is highly probable that the Manx rock is of Lower-Carboniferous age, we appear to have evidence of the eruption of closely allied rocks in the South of Scotland, the Isle of Man, and the West of Ireland in the Carboniferous period.

It ought to be mentioned that the specific gravity of the Manx rock (2·77 to 2·81) does not agree very closely with that of the Lion's Haunch rock, which is 2·92 to 2·93; but the relative abundance of olivine may make a great difference in specific gravity.

(e) *The Picrite-porphyrite.*—A dark-green coarsely-crystalline rock with large black porphyritic augite-crystals embedded in a compact green groundmass. Specific gravity 3·02 to 3·04.

A section cut for the microscope shows that the rock consists chiefly of very large idiomorphic augite-crystals, brownish by transmitted light. One of these, of rather over average size, measured 5 millim. from clinopinacoid to clinopinacoid × 3·8 millim. from orthopinacoid to orthopinacoid. Zone-structure is very well developed. Successive parallel bands of brownish granular inclusions following

* Teall, 'Brit. Petrogr.' pl. xxiii. fig. 1.

† Quart. Journ. Geol. Soc. vol. xxxi. (1875) pp. 131–148.

‡ 'On . . . . Limerick Carboniferous Trap-rocks,' Geol. Mag. (1873) pp. 157 & 158.

the contours occur. Twinning is common; but perhaps the most remarkable feature is the occurrence of irregular aggregates of augite, which by ordinary light look like single crystals, but by polarized light are seen to consist of perhaps half a dozen individuals, often twinned, with irregular boundaries where they meet. The augite crystals are sometimes traversed by cracks occupied by green fibres, lying at right angles to the cracks; these fibres are probably chlorite. Patches of magnetite or ilmenite occur.

The matrix in which the abundant augite-crystals are embedded is now a confused mass of green alteration-products, by which it is hard to say what original minerals are replaced. I hesitate to give a name to this rock; but, as I believe olivine to have been originally present, I propose to term it provisionally an augite-picrite-porphyrite.

(f) *The Olivine-dolerite Series.*—I use the word "dolerite" as a general term (as Rosenbusch uses "basalt") irrespective of the coarseness of grain or compactness of the rock.

The rocks are, when fresh, dark coloured, almost black, save where the abundance of olivine gives them an olive tinge. They weather green internally, and dark brown or sometimes ochreous at the surface.

As is usually the case, there are differences in coarseness of grain according to the width of the dykes and the distance from the salbands. A specimen from Grenea, near Strandhall, is most compact, though pseudomorphs of porphyritic olivine can be made out with a lens; No. 81 (23-feet dyke at Strandhall) is the most coarsely crystalline, but differs from the rest in appearance, being speckled with white owing to the abundance of analcime. As a rule the porphyritic olivines are the only minerals which can be made out. They are best seen in some of the dykes at Langness. Small amygdules and pseudo-amygdules are common. The specific gravity of No. 189 (35-feet dyke north of the Goayr) = 2·90; No. 192 (12-feet dyke south of Martha Gullet) = 2·92; No. 196 (2-feet dyke near the northern copper mine, Langness) = 2·89.

Sections cut for the microscope give the following data:—

| *Original Minerals.* | *Secondary Minerals.* |
|---|---|
| Olivine. | Serpentine. |
| Augite. | Chlorite. |
| Plagioclase. | Calcite. |
| Magnetite. | Magnetite. |
| Picotite. | Analcime, and |
| Apatite. | perhaps other Zeolites. |

The structure is ophitic, and in many cases distinctly porphyritic, the most porphyritic specimens being 189, 192, 196, &c. The porphyritic constituents are olivine, picotite (included in the olivine), and in some cases plagioclase. The rock is in most cases holocrystalline, but possibly Nos. 81 and 166 (4-feet dyke at Strandhall) may be exceptions, and the occurrence of amygdules, in some cases, leads one to infer the original presence of glass.

Olivine occurs as large, frequently idiomorphic, crystals, bounded by the usual pinacoid and dome faces. It is almost completely fresh in 189, 192, 196; it is more frequently partly fresh and partly represented by serpentinous pseudomorphs, and is wholly represented by pseudomorphs in most cases. The olivine is sometimes corroded by the groundmass; this is best seen in 166, 189, 192, 196, &c. Aggregates of olivine crystals frequently occur.

The augite is violet-pink in colour by transmitted light, and is in almost all cases distinctly ophitic. The ophitic structure varies from the large coherent plates into the margins of which felspars project in No. 81 to the, if I may so term it, trellis-like ophitic structure of the 23-feet dyke at Knockrushen, where the augite is cut up into small, usually triangular, sections by a trellis-like network of felspars.

The plagioclase occurs both as a porphyritic constituent and in the groundmass. The porphyritic plagioclase gives lath-shaped sections; it is present in 189, 192, 196, &c. In the other sections only one generation of plagioclase, viz. that of the groundmass, occurs; this also gives lath-shaped sections. According to Mr. Rutley (in Messrs. Dickson and Holland's paper *) the plagioclase in three specimens, judging from the extinction-angles, was anorthite, while in one specimen felspars which "may probably be referred to bytownite" were also present.

Magnetite (or ilmenite) is abundant, and appears to belong to the groundmass. It also occurs as a secondary product in the olivine pseudomorphs, *e. g.* in Nos. 81 and 189.

The picotite (or chromite) occurs as yellowish-brown idiomorphic crystals of small size included in the olivine, and is therefore an intratelluric porphyritic constituent. The only section in which I failed to observe it in the olivine or pseudomorphs is No. 81.

Apatite in acicular crystals up to ·5 mm. long is abundant in No. 81, in which also pyrites occurs.

Serpentine, as a product of alteration of the olivine, is abundant; it occupies irregular cracks, or completely replaces the crystal as a pseudomorph with mesh-structure.

Chlorite is present as an alteration-product of the augite.

Calcite occupies amygdules and pseudo-amygdules.

Analcime occupies the angular spaces between the felspars in Nos. 81 and 166, and either partially or completely fills amygdules in 166. It is generally isotropic, and often exhibits brownish granular cloudy patches, as does the analcime in the dolerite of Salisbury Craigs, Edinburgh †.

Section 189 (35-feet dyke N. of the Goayr, Langness) differs so much from most of the other sections of olivine-dolerites as to deserve special description. The most distinctive points about it are the marked contrast between the fine-grained groundmass and the porphyritic constituents.

* Proc. L'pool Geol. Soc. vol. vi. pt. i. (1889) pp. 129, 130.

† See also Teall, 'Brit. Petrogr.' (1888) pl. xxii. fig. 1, Analcime-diabase of Car Craig.

The porphyritic constituents are large, fairly fresh crystals of olivine. These are idiomorphic, and show the brachypinacoid (010), combined with the brachydome (021). An average-sized crystal measured ·775 millim. long from the acute angle between the brachydomes (021) to the similar opposite angle. A large specimen was twice as long. The angles in some specimens are rounded, in others sharp. The crystals are traversed by irregular cracks, along which alteration has taken place, the centre of the cracks being occupied by black iron-ore (magnetite?), with green serpentine on each side of it. In most cases not more than a quarter of the area of each crystal has been thus altered, the spaces between the cracks being almost unaltered. In many of the olivine-crystals are inclusions of chromite or picotite. In several instances the olivine crystals are corroded by the groundmass, which occupies gulf-like spaces in them. These gulfs are often partly occupied by porphyritic plagioclase crystals; indeed the porphyritic plagioclase is most abundant around the corroded olivines, and seems to have been formed in connexion with their corrosion, in these cases the lath-shaped crystals being often in close contact with the olivine, and having their length parallel with its margin.

The porphyritic plagioclase occurs in lath-shaped sections; an average specimen measured ·625 millim. long × ·050 broad, a large one ·915 millim. long × ·105 broad. Although in most cases the porphyritic plagioclase is well marked off from that of the groundmass, yet crystals occur of which it is difficult to say whether they belong to the intratelluric period or to the groundmass.

The groundmass consists largely of small lath-shaped plagioclase crystals or microlites. A lath of average size measured ·09 millim. long × ·006 millim. broad. The space between the felspar microlites is filled with apparently ophitic augite and grains of magnetite. It must be noted that the groundmass forms the great bulk of the rock, the porphyritic constituents occurring in it as isolated crystals or aggregates. It varies considerably in the same section. In some parts felspar microlites are comparatively scarce, and a very finely granular, greyish, faintly double-refracting groundmass is present.

Glassy base not made out with certainty. The structure of the groundmass appears to be pilotaxitic*.

## VI. Supplementary Observations.

Section 250.—About 170 feet S. 63° E. of the western end of the causeway connecting St. Michael's Island (Fort Island) with Langness, there occurs in the slates an igneous rock differing considerably in appearance from that at Gullet Buigh. It is exposed both below high-water mark and in the field above the reach of the tide.

The rock is medium grained, mottled dark green and white, and weathers brown. The dark green colour is due to hornblende, the crystals of which can be readily made out, embedded in a matrix of white or greenish altered felspar. Sp. grav. 2·95.

* Rosenbusch, 'Mikr. Physiogr. d. massig. Gest.' (1887) pp. 466, 727.

In microscopic section the rock shows hornblende, brown by transmitted light, pleochroic in green and brown tints, in great abundance in idiomorphic crystals. The rest of the rock appears to consist of allotriomorphic felspar, quartz, leucoxene, iron pyrites, and (subject to correction) abundant secondary epidote and some calcite. I take the rock to be a diorite.

There is some similarity in mineral composition between this rock and that which I have described as a diabase [521] from Gullet Buigh, although hornblende is very abundant in 250 and scarce in 521. Possibly further investigation may show them to be different rock *facies* assumed by the same original magma.

Section 252.—About one mile west of Port Soderick is a farmhouse called Oatland, and nearly 370 yards W.S.W. of the farmhouse an igneous rock is exposed in a small quarry in some uncultivated ground.

The rock is fine-grained and not dark-coloured, the colour being mottled green and white. With a lens small idiomorphic white felspar-crystals are readily made out; quartz is abundant, and the green constituent is an altered mica. Sp. grav. 2·72.

In microscopic section small, cloudy, much altered, but very idiomorphic felspars are abundant. They vary in size from 4 millim. × 1·7 millim. to ·64 millim. × ·21 millim., and appear to be chiefly plagioclase. Quartz is abundant and allotriomorphic, forming the matrix in which the other constituents are embedded, and it frequently exhibits undulose extinction. The altered mica is green, with distinct pleochroism, light green for rays vibrating parallel with the cleavage-cracks, light straw-yellow for those at right angles to that direction. This agrees with the pleochroism of chlorite.

Associated with the altered mica is secondary epidote, varying from brown to yellowish green in colour and exhibiting the green interference-colour of the third order, while the quartz shows the yellow of the first order. The rock is a granite (in the wide sense), and is quite distinct from that of Foxdale.

Sections 203 and 2388.—Between Poortown and Rockmount, in a quarry on the north side of the road 260 yards east of the Poortown picrite-porphyrite quarry, a large mass of igneous rock is exposed. The rock is dark grey with greenish flecks, and is compact, breaking with a clean, sharp, splintery fracture. Specific gravity 2·80.

Much-altered porphyritic felspars are embedded in a groundmass of felspar-laths and iron ore, the latter mostly changed to leucoxene. The spaces between the felspar-laths of the groundmass are occupied by green alteration-products.

This rock bears a considerable resemblance microscopically to the augite-porphyrite [500 A] at Scarlet Point. From an examination of a microscopic section kindly lent to me by Mr. Dickson I believe this to be the same rock described by Messrs. Dickson and Holland* as "specimen of gabbro from the most westerly quarry

* Proc. L'pool Geol. Soc. vol. vi. pt. i. (1889) p. 128.

at Rockmount. . . .about the exact character of which there seems to be some little doubt," and of which Mr. Rutley says, "The constituents are labradorite, serpentine pseudomorphous after olivine, and possibly in some cases after pyroxene, ilmenite, magnetite, and some calcite." The specific gravity, 2·26, quoted for the specimen analysed is erroneous; it should be 2·76. The hand-specimen does not agree very well with that collected by me. The silica percentage agrees closely with that of the augite-porphyrite (termed by Mr. Rutley "altered basalt") of Scarlet Stack, but the percentage of lime and magnesia is much higher.

## VII. Summary.

Omitting from consideration the Foxdale granite, the oldest igneous rocks of the south of the Isle of Man appear to be the Diabase series which occurs as dykes with a prevalent north-easterly strike, intrusive in the Lower-Silurian slates. These dykes, best seen at Langness, are of pre-Carboniferous age, as they do not penetrate the Carboniferous basement-conglomerate.

The micro-granite dyke at Crosby is interesting from the parallel structure of its salbands. It is intrusive in the Lower-Silurian slates and is probably newer than the Foxdale granite*, which appears to be post-Lower Silurian, since it has altered the slates and thrown them into an anticlinal, and pre-Carboniferous, since the Carboniferous conglomerate overlies the slates almost horizontally at Langness.

We next meet with volcanic rocks of Lower-Carboniferous age. This is the augite-porphyrite series, and consists of tuff, breccia, agglomerate, bedded lava, and intrusive masses, exposed in a narrow strip a mile and a quarter long, extending from Poolvash (Poyll Vaaish) to Scarlet Point. The succession of events appears to have been as follows:—During, or after, the deposit of the Poolvash limestone a vent was opened from which fine volcanic ashes were ejected and fell into the sea, forming bedded tuff. At intervals between the eruptions the black, so-called Poolvash marble was deposited, and thus came to be interstratified with the tuff. Probably the vent became plugged up, and the violent eruption accompanying the blowing up of the plug provided the material for the agglomerate which overlies the tuff near Scarlet Point. Then lava welled forth and overspread the agglomerate. Finally the volcano became extinct, and by denudation the intrusive mass of the Stack, which I regard as a volcanic neck, was exposed. It was probably at the close of the volcanic activity that a melaphyre dyke containing porphyritic plagioclase, augite, and pseudomorphs after olivine, and resembling the porphyritic olivine-basalt of the Lion's Haunch, Edinburgh, was formed.

At Poortown, north-west of St. John's, there occurs an intrusive

* See Cumming's 'Isle of Man,' p. 175.

mass of igneous rock, which I provisionally term augite-picrite-porphyrite. The same rock is said by Cumming to occur at Cronk Urley (Urleigh) and Port St. Mary, and Cumming considers it to be of post-Carboniferous age.

Numerous dykes of ophitic olivine-dolerite with a prevalent north-westerly strike occur between Bay-ny-Carrickey and Castletown Bay, at Langness, &c. They are of post-Lower Carboniferous, and possibly of early Tertiary age. Among the "Supplementary Observations" a diorite at Langness, a granite at Oatland, near Port Soderick, and a basic igneous rock at Rockmount are described. A duplicate series of sections of the rocks described will be deposited in the Owens-College Museum.

In concluding this paper I wish to express my thanks to Prof. W. Boyd Dawkins, F.R.S., who has accorded me the free use of his maps and notes in connexion with his survey of the Isle of Man on the six-inch scale, to which the present paper forms a contribution.

## Plate XIV.

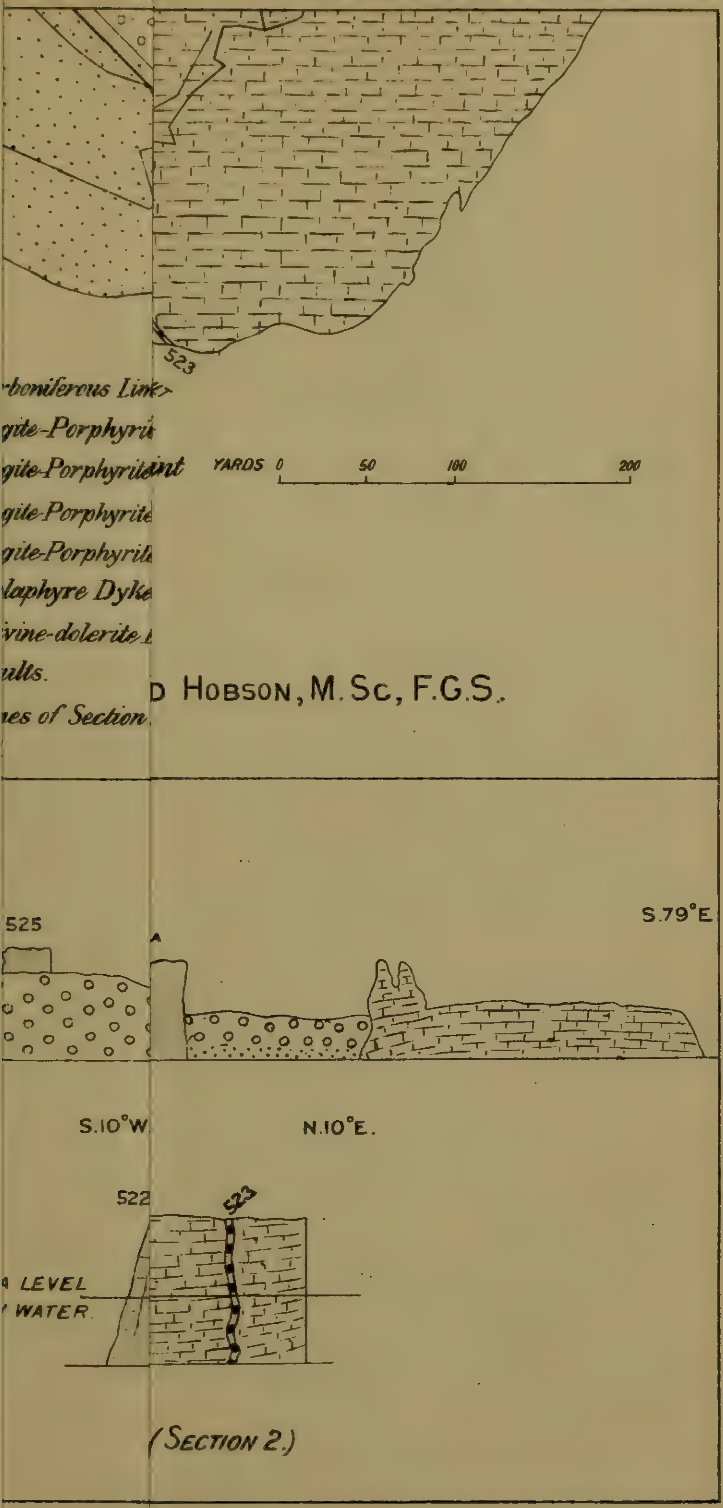
Geological Map of the South of the Isle of Man and sections through Scarlet Point, Isle of Man.

## Discussion.

Prof. Boyd Dawkins said that the paper was a first instalment of the results of the geological mapping on the six-inch scale of the Isle of Man which he had been carrying on for several years, and in which he had been assisted by the Author. The igneous rocks of the island presented points of considerable difficulty. The Author had, in his opinion, made a valuable addition to our knowledge.

Mr. Rutley inquired what was the relation of the picrites to the other members of the volcanic series, and commented on the very careful manner in which the Author had described the rocks.

The Author, in reply to Mr. Rutley's query, explained that the igneous rocks at Scarlet Point belong to two distinct periods, the augite-porphyrites being of Lower-Carboniferous age, while the olivine-dolerite dykes are certainly post-Lower Carboniferous, and perhaps of early Tertiary age.


523
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D HOBSON, M. Sc, F.G.S.
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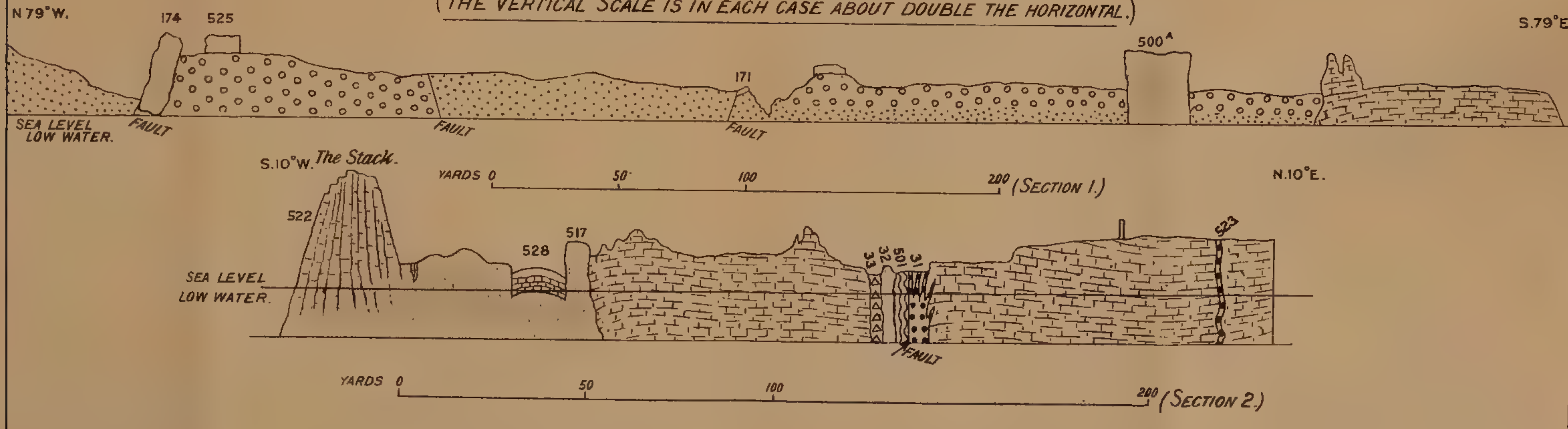
S.10°W.
N.10°E.
522
523
A LEVEL
WATER
(SECTION 2.)


GEOLOGICAL MAP OF THE SOUTH OF THE ISLE OF MAN. BY BERNARD HOBSON, M.Sc., F.G.S.

SECTIONS THROUGH SCARLET POINT, ISLE OF MAN.

(THE VERTICAL SCALE IS IN EACH CASE ABOUT DOUBLE THE HORIZONTAL.)



## 25. *A* Contribution *to the* Geology *of the* Southern Transvaal.

By W. H. Penning, Esq., F.G.S. (Read February 25, 1891.)

(Abridged.)

[Plate XV.]

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### I. Introduction.

(a) *The Southern Transvaal.*—The area occupied by the Witwatersrand beds offers many facilities for accurate observation. I have been enabled to collect sufficient evidence to fairly establish the relation between the geology of the district and that of the older known gold-fields, and thus to briefly describe the geology of the Southern Transvaal *. The accompanying map (Pl. XV.) shows an area about 350 miles in length and 50 miles in breadth (or 17,500 square miles in extent). Some points require further elucidation; but the geological features, as expressed on the map and sections, are generally correct according to my interpretation.

For a description of the district here referred to and its eastern border, see Quart. Journ. Geol. Soc. vol. xl. (1884) pp. 658 *et seqq.*, with map and sections.

The granitic rocks are most frequently fine-grained, and generally include little mica, but sometimes much hornblende. Whether pegmatite, syenite, or granite, they are comparatively little exposed in the Southern Transvaal.

The granite (*a*, on map and sections) is frequently broken through by dykes of diorite, which almost always run nearly north and south. So also are the stratified rocks of all ages broken through in this way; but the older these are the more numerous are the dykes within them. In the granite, the various minerals have sometimes been re-assorted by the effects of the dykes—layers of quartz and felsite, or of kaolin, flanking the dykes on both sides for considerable distances.

* Quart. Journ. Geol. Soc. vol. xli. (1885) pp. 569, &c.

The general absence of fossils makes it very difficult to assign the several formations to their proper geological position; and it is therefore convenient to continue the use of local names. The only formation that can yet be approximately classified is the newest of all, that which in 1884 I described as the "High-Level Coal-fields of South Africa"*, and which I take to be of Oolitic age. The evidence is, first, the *Glossopteris* (?) found in the sandstones in 1884; and, secondly, a block of sandstone recently brought from the Free State, which shows casts and impressions of fishes like *Lepidotus* †. The various formations in the Transvaal are provisionally classified as on the opposite page:—

(b) *The De-Kaap Valley and Northern Swaziland.*—The oldest series of stratified rocks in this region is that here provisionally called the "De-Kaap Valley Beds" (*b*, on the map and sections), and which I believe to be of Silurian age, although there is no fossil evidence except that of a few obscure corals. See my description of these deposits, Quart. Journ. Geol. Soc. vol. xli. (1885) p. 571.

In a southerly direction this series passes through Steynsdorp with diminishing width of outcrop; and this strengthens my argument that a great break has let down the beds against the granite, along the inner side of the mountains forming the border of Swaziland, from the N.E. corner of that country as far as the Komati River. In a similar manner the same beds terminate on the north against another fault that runs nearly parallel with the Crocodile River; and these two faults will probably be found to coalesce a few miles to the eastward.

One additional section may be given,—that of the beds immediately enclosing the well-known "Sheba Reef":—

On the S. side of Sheba Creek, a deep gorge shows at least 1000 feet

Schists and flagstones.

On the N. side of the Creek,

Quartz-schist, over
Quartzite.
Quartzite, auriferous; "Sheba Reef," richest on upper side.
Schists and flagstones.

Dip S. 45°.

## II. The Megaliesberg Formation.

When the paper to which reference has been made was written, the gold-fields of the Witwatersrand were unknown, but those of Lydenburg were even then considered by me to lie on the Megaliesberg formation (Devonian?)‡. I then stated that "at the base of these Devonian rocks (especially at the Devil's Kantoor) is frequently seen a series of conglomerates and sandstones . . . . . formed from

* Quart. Journ. Geol. Soc. vol. xl. pp. 658 *et seqq.*

† The photograph sent by the Author is recognized by Mr. A. S. Woodward as showing *Semionotus capensis*, A. S. W., Quart. Journ. Geol. Soc. vol. xliv. (1888) pp. 138–140, pl. 6, figs. 1–5.—Editor.

‡ Quart. Journ. Geol. Soc. vol. xli. (1885) p. 576.

*Tabular Comparison of the Terms used by some Authors.*—(In descending order.)

| *Dunn* (Map 1887). | | *Stow.* | *Jones.* | | *Penning.* | | |
|---|---|---|---|---|---|---|---|
| Coal-measures: UPPER KAROO (formerly Stormberg Beds, above UPPER KAROO). | CARBONIFEROUS TO TRIASSIC. | UPPER KAROO. | UPPER KAROO. | PERMIAN TO TRIASSIC. | High-Veldt Beds. | | OOLITIC. |
| Kimberley Shales: LOWER KAROO (formerly UPPER KAROO). | | [Olive shales of the Karoo Formation.] | LOWER KAROO. | | Kimberley Beds. | | |
| Lydenburg Beds. | SILURIAN. | [Campbell-Randt or Kaap Rocks, and the old schists of the Vaal.] | | | Klip-River Series. | Megaliesberg Formation. | DEVONIAN. |
| | | | | | Witwatersrand Series. | | |
| Namaqualand Schists. | | | | | De-Kaap-Valley Beds. | | SILURIAN. |

the waste of the underlying Silurian beds." The conglomerates, and in a less degree the sandstones, are auriferous. Subsequent observations convinced me that the inference was correct, and that the Lydenburg rocks referred to later on are of the same age as those, 200 miles distant, now to be briefly described.

As in the De-Kaap Valley and Northern Swaziland, so between Pretoria and Johannesburg, the rocks have been partly tilted by, and partly faulted against, a mass of granite, which, by its more rapid disintegration, here also forms the lower ground, surrounded by the tilted and broken stratified deposits. This upheaval was more recent than that of the De Kaap, as in the latter region the Silurian (?) rocks only were disturbed, whilst the Devonian (?) still occupied very nearly their original horizontal position.

(a) *The Witwatersrand Series.*—These rocks have been described as "chiefly sandstones, sometimes micaceous, with occasional shales, cherts, and quartzites, especially towards the base of the formation, which abuts against the mass of granite already mentioned. The intrusion of this granite has tilted the rocks to a high angle . . . . further south they gradually assume a less inclination, and eventually are seen in a nearly horizontal position" *. Here they pass in under a very large and quite conformable sheet of dolerite, the outcrop of which (from beneath an upper series of strata) has recently been traced south-eastward to beyond Heidelberg, the beds rising from beneath it, in due order, all round its eastern extremity, and again along its southern margin. This establishes as a fact, what was previously only a surmise, that they form a practically continuous basin, the southern extension of which passes in under the Coal-formation to an indefinite distance in the Orange Free State. From several sections across this basin, and many observed dips all over the area, I have worked out the curve which these beds must follow in their downward course; and, as the results fairly tally at distances of some miles apart, they may be taken as approximating to the truth. I find that the surface of the granite along the central line of the basin, if assuming as regular a curve as the outcrops indicate, would lie at a depth of about 18,000 feet below the ground; and, as this has an average elevation of about 5000 feet, the granite along that line is no less than 13,000 feet below the level of the sea.

Of this fact the continuity of the beds all round the eastern end of the depression, with mere local fractures and without much change in thickness, affords satisfactory evidence. The regularity of the lessening dip implies general absence of folding; and, even if the beds be folded, there must still be room for their great thickness, unless (as is unlikely) they have thinned out towards what is now the middle of the depression. The width of outcrop of the rocks of this series near Johannesburg is five miles, and their dip decreases from almost 90° through 60°, 45°, and 20° to 10° (where they pass under the dolerite), with an average of about 40°, which

* Journ. Soc. Arts, vol. xxxvi. (1888) p. 435.

would give them a thickness of about 17,000 feet, thus corroborating the estimate of 18,000 feet obtained from the assumed regular curve in the present lines of their stratification. There may be nothing unusual in such hollows in the granite, whether above or even far below sea-level; but a consideration of this basin (now so far inland and so high at its edges) suggests to me that the Megaliesberg formation may possibly have had a marine origin, and not necessarily have been, as hitherto generally supposed, formed at the bottom of a lake at a considerable elevation. The great basin may certainly have been formed by subsidence of its centre, and not by upheaval around its margin; or there may have been both upheaval and depression. It is geologically and practically interesting to determine whether the granite ridge completely circumscribes this Rand basin, and so forms a huge circular bowl filled by the lower part of the Megaliesberg formation, some 60 miles across and 18,000 feet deep; or if it has an outlet or an extension carrying these auriferous deposits into unknown areas trending towards the Atlantic Ocean.

The foregoing observations establish a minimum thickness of 17,000 feet for the Witwatersrand series, uninterrupted by volcanic disturbances except so far as the intrusion of some few diorite dykes is concerned. To a later period of intermittent outbursts may be attributed the more crystalline nature of the rocks of the upper series, which encloses many interbedded trap-rocks extending over large areas; the first of these being the thick sheet of dolerite (*d*, of the map and sections) already referred to, which forms a distinct line of demarcation. Both series of strata are persistent over very large tracts, especially the auriferous conglomerates ("bankets"),—a feature admitting of their identification from one side of the basin to the other. This fact, with the unbroken outcrops and inward dip around the basin, proves that each series of "bankets," and apparently the individual deposits (with some exceptions, due to thinning-out), are continuous. As regards the agency by which such extensive beds of gravel, a few feet or even a few inches only in thickness, can have been so evenly distributed, I confess my inability to offer a satisfactory suggestion.

Ferruginous shales occur amongst the sandstones (which are often false-bedded and ripple-marked), most frequently between what is called the "Main Reef" and the lower beds of the formation, one series of them invariably enclosing a band of magnetic iron-ore of peculiar character and appearance. By a process of chemical segregation, this iron ore has been concentrated along distinct bands, black, brown, or red in colour, leaving white streaks between, but not always following the lines of lamination; the banding may be straight, wavy, contorted, or folded; but there is neither much folding of the beds nor contortion. There are two, three, or more of these magnetic beds in some places, but the chief one, which powerfully affects the compass, is (or certainly appears to be) continuous around the end of the basin, having been traced all along the Rand, round by Heidelberg, and across the Vaal River

into the Free State; indeed, it has been the chief clue in following and identifying the "Main Reef" from the Rand, west, east, and south, for some 200 miles.

There are talcose and chloritic slates, which, if not so persistent as the magnetic beds, maintain their relative positions for great distances, and micaceous sandstones, by which certain "banket" series can be recognized,—also most of the "reefs" contain pebbles of a distinct character, and one set of conglomerates differs from the others in enclosing numerous angular fragments of shale.

(b) *The Klip-River Series.*—This series of rocks (*e*), previously called by me the "Megaliesberg beds," proves to be part of a larger "Megaliesberg formation," which includes the equivalent of the "Klip-River" (or upper) series, and the "Witwatersrand" (or lower) series already described. It consists of "shales and flagstones, fissile and thin-bedded, which generally are grey, but weather to yellow, or dirty-yellow, or dirty-brown. In some localities, as along the valley of the Eland's Spruit, there occurs a series of cherts and quartzites, which appear to replace the lower shales" *. These cherts and quartzites also form the lower part of the series around Pretoria and at the Klip River, the shales being in much greater force (where first observed) in the Lydenburg district; there occur throughout numerous interstratified traps, sometimes of great thickness. This series is at least 18,000 feet thick; and from its southern edge, by the granite near Pretoria, across the mountains from which the formation derives its name, it is actually seen, and its thickness can be determined, independent of any inference as to the curve formed by underground extension.

Near its base, this series has a distinctive "banket," called the "Black Reef," amidst sandstones and quartzites, which again are overlain by a peculiar rock, which I described as chalcedolite †, in connexion with the Lydenburg district, and which confirms my opinion of that area forming part of the Megaliesberg formation. By weathering it often presents most fantastic characters. This chalcedolite, including the "Black-Reef" banket, comes close to the granite south of Pretoria, the whole of the lower series being absent; and, as it seems impossible for the latter to have absolutely thinned away, and improbable for it to have been entirely overlapped against the mass of granite, I have come to the conclusion that it is faulted down, and must exist below in its relative position.

The base of this series, generally conformable to that below, is traceable on the south along the valley of the Klip River (whence its name), then across the Vaal, here and there under the Coal-formation, into the Free State, and again into the Transvaal near Klerksdorp; here it is faulted down against the lower series of rocks which then dip *westward*. This is perhaps a mere local disturbance, but it may indicate the commencement of another basin, in which, as previously suggested (p. 455), the Megaliesberg formation may be carried in that direction to a great distance, to reappear possibly even so far west as Bechuanaland.

* Quart. Journ. Geol. Soc. vol. xli. (1885) p. 576. † *Ibid.*

In view of the great persistence of certain beds over large areas in this region, I am inclined to think that, as already stated, the auriferous conglomerates of the Devil's Kantoor, and the chalcedolites of the Blyde River and elsewhere in the Lydenburg district, establish the position of the rocks of that district as part of the upper series of the Megaliesberg formation. They need not again be described; but it may be repeated that "the chief exposure of the chalcedolites is along the Blyde River, best seen on its western side or escarpment, where the rock occurs in two series," as it does near Pretoria, "the lower several hundred feet in thickness. . . . . It contains fine gold in places, and, where in a decomposed state, it has been worked as so-called 'rotten-reef' to a considerable extent" *.

As previously mentioned, the De-Kaap-Valley beds are faulted, on both the north and the south, against the granite, the lines of fault probably coming together in the region to the eastward. In a similar manner the whole of the lower half of the Megaliesberg formation is let down against the north side of the granite S. of Pretoria, and against its east side by a fault at nearly right angles to the former. Another line of fracture branches off to the east, bringing the upper half of the formation directly against the lower, but with a possible intrusion of trap-rock along the line; the geology hereabouts is, however, very obscure, and the tilted rocks soon pass in under the newer formation of the next section. I am inclined to the opinion that the Pretoria E. and W. fault extends even down to Klerksdorp (across a district at present unknown to me), where, as in the preceding instance, the upper series abuts directly against the lower, as shown in the section (Pl. XV. fig. 1). Also, that another E. and W. fault will be found to occur north of Pretoria, letting down the beds that form the Megaliesberg Range against the granite which is known to appear at the surface not very far north of the mountains.

## III. The High-Veldt Coal-formation.

The newest formation of all here is that which I described in 1884 as the High-Level Coal-fields of South Africa †. It rests unconformably upon the older rocks, and, with local exceptions, very nearly maintains its original horizontality. Some important coal-seams are now known to be continuous for many miles; and I feel still more convinced of the lacustrine origin of coal.

The "Kimberley Beds" (*g*) make up the lower portion of this coal-formation on the west, but thin out eastwards, and are overlapped near Klerksdorp by the "High-Veldt Beds" (*g'*) or upper portion, the estimated thickness of which is 2300 feet. The amygdaloidal dolerite (*f*) upon which the "Kimberley Beds" rest, and which is met with at a depth of 300 feet in the Kimberley Diamond Mine, has now been traced eastwards to a great distance. It crops out at

* *Op. cit.* (1885) p. 577.

† Quart. Journ. Geol. Soc. vol. xl. p. 658.

the Vaal River near Barkly, and may then be followed up along the valley, past Christiana and Bloemhof, to Klerksdorp, where it overlies the Witwatersrand series. Thence it rises to cap the Gats-Randt, where it rests on the Klip-River series, and its outcrop makes a clear line of demarcation between the High-Veldt coal-deposits and the Megaliesberg formation.

Brief mention may also be made of a volcanic rock (*h*), of which but few small patches remain, overlying this coal-formation. East of Boksburg it caps a small hill as a bluish-grey basalt, which weathers into rounded lumps of a dark-brown colour. North of that place it is seen in section overlying grey and black paper-shales, sometimes micaceous, with coarser sandstone below; here the volcanic rock is weathered into a soft grey mass with numerous small concentric nodules. In this locality, and near the base of the formation, there is a bed of loose, calcareous, sandy clay, enclosing many waterworn pebbles, some of large size, derived from the "bankets" and quartzites of the subjacent formation; this is an old alluvium to which further reference will be made.

A few additional sections may be enumerated as follows:—

East of the Wilge River, the Holfontein mines give a good section:—

| ft. | in. | |
|---|---|---|
| | | Coarse sandstone. |
| | | Shale. |
| 21 | 0 | Coal, with a constant thin parting of shale about the middle; the best coal below. |
| | | Sandstone. |

On the farm "Witklip," forty miles E. of Johannesburg, in the "Greville Colliery," the following section is obtained:—

| ft. | in. | |
|---|---|---|
| 20 | 0 | Loam, over calcareous clay. |
| 4 | 0 | Sand and pebbles. |
| 11 | 0 | Shale, dark in colour. |
| 3 | 0 | Sand and pebbles. |
| 19 | 0 | Shales. |
| 4 | 0 | Shales, with thin layers of coal. |
| 15 | 0 | Coal. |

The Boksburg Collieries have seams of coal of varying thickness. The "Brakpan" colliery-shaft goes down 58 feet to coal, which is over 20 feet thick, including a bed of sandstone about a foot thick.

South of the Zuikerbosch-Randt River, on the farm "Modderfontein," two pits, 14 feet deep, show:—

| ft. | in. | |
|---|---|---|
| | | Grey sandstone. |
| 0 | 3 | Shale. |
| 6 | 0 | Coal. |
| | | Sandstone. |

South of the Vaal River, opposite Klerksdorp, the mine of the Kroonstad Coal-Company is in—

| ft. | in. | |
|---|---|---|
| 20 | 0 | Yellowish sandstone. |
| 0 | 6 | Yellow and purple laminated clay. |
| 0 | 3 | Micaceous shale. |
| 1 | 4 | Shaly coal. |
| 0 | 6 | Shaly coal, ferruginous. |
| 1 | 2 | Good coal. |
| 0 | 4 | Finely laminated coal. |

## IV. Denudation.

As in all other parts of the world, there has been here enormous denudation of the more ancient rocks, resulting in the most marked unconformity between the Silurians (?) of the De-Kaap Valley and the Devonians (?) of the Godwaan Plateau. Some points in the later planings-down of this region are well worthy of consideration, both in that (*a*) which preceded the deposition of the coal-bearing rocks, and in that (*b*) to which the present surface-configuration is due.

(a) *Before the High-Veldt Coal-formation.*—In treating of the auriferous rocks I have not commented upon their characters as gold-producing rocks; but in one respect the occurrence or non-occurrence of that metal, or of any other metal or mineral, in them (or in deposits resulting from them) may afford strict geological evidence. Such evidence will be of even more value in connexion with gold, which under ordinary conditions cannot travel far, as its absence from rocks where its presence would naturally have been surmised renders more probable any explanation of its removal by extraordinary or unexpected agencies.

The tilting of the Witwatersrand series began at that period of volcanic activity which gave rise to the outpouring of the dolerite (*d*) in an extensive sheet that can even now be traced for a distance of at least 300 miles. But this evidently slow upheaval still continued at the same centres, as the trap-rock also was turned up with the beds beneath it, and now forms a fringe to the Klip-River series around the inner part of the Rand basin. Meanwhile the upper series of rocks were deposited, and in some places overlapped the bent-up, faulted, and locally-denuded edges of the Witwatersrand series, as for instance some twenty miles west of Johannesburg. Even then there must have been extensive denudation going on over the areas upheaved, that is to say above the granite bosses south of Pretoria and at Parys in the Orange Free State; a similar argument to that which follows, although in reference to a still earlier period, in connexion with the upheaval of the beds of the De-Kaap Valley, might also apply.

It might naturally be expected that large alluvial deposits of gravel, as such or as old conglomerate, would result from the removal of the masses of rock that once overlay these granite centres, especially as many of the beds consisted of conglomerates, and were made up, to a great extent, of pebbles of hard quartz and quartzite. But, as a matter of fact, the country is almost destitute of alluvial deposits worthy of the name. There are some few of recent origin,

and these generally contain nuggets of gold; but both their mass and their auriferous value are very small in proportion to the rocks which have been removed. The point, however, is this: admitting the power of the streams to have carried away the sand and clay resulting from ordinary disintegration of these rocks, the gold must have remained behind with the heavier minerals that cannot be transported far by ordinary agencies. Yet the absence of alluvial gold is remarkable, and leads to the conclusion that the denudation of the period in question was not due to *rain and rivers*. Equally difficult is it to believe that it could have been marine; and, at first, it may seem still more difficult to account for the absence of gold-bearing alluvia, as I now suggest, by the action of ice, in a region lying between the 25th and 27th parallels of south latitude.

Previous observers have mentioned traces of glacial action in South Africa, and Mr. E. J. Dunn has described and mapped the Dwyka conglomerate as glacial; but, although always on the look-out for them, I have seen such traces only in two instances. It has even been asserted that the whole of the western slope of the Drakensberg shows signs of glaciation. This is certainly not correct so far as the Transvaal is concerned, whatever may be the case farther south along the extension of that range in the Free State and the Cape Colony. What traces there may once have been on the mountains have long since disappeared; and, as I am now inclined to believe, those at lower levels are covered over by the coal-formation deposited long after the (now assumed) glacial period of this region.

In 1881, when visiting the River-Diggings, where the first diamonds were found, I made the following note:—"*Roches moutonnées*, striated, in short valley running in at lower end of Winter's Rush," a point not far above the junction of the Vaal and Hartz Rivers. The striæ follow the direction of the little valley, due west, towards the Vaal River, the recent valley thus following the line of the old, which here is not an uncommon occurrence. Crossing the strip of land between, one comes to another small valley, tributary to the Hartz River; here also were seen striæ running north and south, and thus again coinciding with the direction of the valley. I have another note of an ice-marked boulder (?) near the Modder River, some thirty miles S. of Kimberley, and there are "boulder-clays" (glacial?) near Pietermaritzburg in Natal. It may be admitted that these few observations of glacial markings, 300 miles or more from the locality in question, form a very small basis on which to found a theory of a glacial period in the Transvaal; but it must be remembered that those made near the Vaal River are at 2000 feet less elevation. The basis may be insufficient, but the hypothesis will go a long way towards explaining some minor difficulties (*e. g.* the formation of "pans," thus = "rock-basins") that seem to me otherwise insoluble, as well as the almost total absence of auriferous alluvium in regions containing rich gold-bearing deposits that have been reduced to an enormous extent by erosion—glacial, fluviatile, or marine. Therefore, I am convinced

that this region was under glacial influences at some time during the long period which intervened between the deposition of the Megaliesberg formation, in probably the Devonian era, and of the coal-bearing rocks of the High Veldt, the age of which is certainly Oolitic. Mr. Dunn places the Dwyka conglomerate just above the Carboniferous.

(b) *Denudation of the present Surface.*—Whatever agencies may have effected the denudation of the older rocks of the Southern Transvaal before the imposition upon them of the Secondary High-Veldt formation, those of later date were decidedly fluviatile. The noteworthy feature of this denudation is its apparent continuity from the close of the Oolitic period until now. There are evidences of an enormously prolonged period covered by the last subaerial denudation.

(c) *During the early Part of the High-Veldt Coal-formation.*—Intervening between the two periods of great erosion (*a* and *b*, above) there was another denudation of this area, naturally fluviatile, anterior to and during the deposition of the lower beds of the coal-bearing formation. The alluvial deposits containing gold, resulting from this minor degradation, will be found (I venture to affirm) in the valleys of that period, many of these valleys being more or less coincident with the present depressions. In their lower portions there are still tongues or branches from the main mass of the High-Veldt Coal-formation which, in some cases, may overlie ancient alluvium; indeed, that is the character of the "sand and pebbles" mentioned in one of the preceding coal-sections (p. 458); such deposits would somewhat correspond to the "deep leads" of Australia. The last, greatly prolonged, fluviatile denudation must surely have left numerous relics of its ancient river-courses in the shape of gravels, which will be found to occupy the summits and flanks of the hills within the larger valleys, although very few have yet been detected. Those acquainted with the Quaternary gravels of Europe cannot fail to be struck with the large areas in South Africa, both hill and valley, exhibiting bare rock, only here and there covered by a few inches, or possibly a few feet, of blown sand. Sometimes there are deep patches of loamy soil, but these, when cut into, have more the appearance of rainwash than of fluviatile accumulations.

The De-Kaap, Blyde, and Olifants Rivers have some good gravels along their present courses, and the headwaters of the Limpopo very few, whatever may be the case away to the north of the Megaliesberg Range. The upper portion of the Vaal has muddy banks, with gravel here and there, until it leaves the Transvaal; then there are large masses of terrace-gravel in which were first found the South-African diamonds.

PLATE XV.

Geological Map of the Area between Klerksdorp and the De-Kaap Valley, and three sections.

## Discussion.

Mr. Gibson maintained that the thickness of the Witwatersrand beds, which was stated by the Author to be 17,000 feet, could not be determined, the strata being so greatly faulted and so similar in composition that a complete sequence could not be obtained. So far as he knew them, the rocks mentioned as granite in the paper were schists, gneisses, some granites, and various other highly altered crystalline rocks. The Witwatersrand beds appeared to have been thrust over these crystalline rocks. He considered the Author's view that the coal-bearing rocks had covered so wide an area to be doubtful.

Mr. Alford thought the geological section exhibited fairly correct, but where it showed the De-Kaap Valley as a denuded anticlinal it was certainly open to question. There were very evident signs of folding in the beds of the Makongwa Mountains, which lie to the south-east of the De-Kaap Valley; also farther north, across the Crocodile River. He could not think that sufficient evidence had yet been met with to justify the use of the names of geological systems such as Oolitic, Devonian, and Silurian. He had seen the "corals" alluded to, and very much doubted that they were corals at all. They occur in a bed of steatite which comes in between the granite and the schists of the Makongwa Mountains, and they are exceedingly obscure. Excepting only a few coal fossils, no organic remains had to his knowledge as yet been discovered in the Transvaal. The fossil fishes, of which a photograph was shown, come from the Ladybrand District, in the south-eastern part of the Orange Free State, and are not in any way connected with the Coal-formation. There are some good specimens of these in the Bloemfontein Museum.

The sandstones, quartzites, siliceous schists, and conglomerates of the Witwatersrand form a vast series of rocks which are recognizable under varied conditions over almost the whole of the Transvaal. It appears, therefore, curious to bracket them with the small local beds of the Klip River, which are probably only the denuded and altered remains of the same, and to give the whole the name of a small range of hills such as the Megaliesberg. It remains to be seen how far the series may be capable of subdivision. The Black Reef is a small and very local series of highly ferruginous deposits, which have become notable on account of some parts of it having been found auriferous. The difference of dip in the rocks of the Witwatersrand is interesting, and more so when noticed in relation to the gold-bearing value of the beds.

Prof. Rupert Jones congratulated the Society on the accumulating knowledge of South-African geology, although the several published accounts of observations are imperfect and more or less contradictory. The Author's section, though apparently generalized in character, evidently contains distinct information on some points in the geological structure of the region concerned. From what the speaker had gathered from his friends, the rocks in the Transvaal are much

ries 3.
ef" Series 2.
-Reef Series 1.

HIG

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"Black-Reef" Series
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c Witwatersrand Beds ("Bankets" etc.)
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b De-Kaap Valley Beds ("Sheba Reef, etc.) ?Silurian
a Granite
d Dolerite Contemporaneous with the Megaliesberg Formation
f Dolerite Posterior to the Megaliesberg Formation & probably to the High-Veldt Formation.
h Posterior to the High-Veldt Formation.
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Macmac
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Lomati R.
Barberton
Pretoria
Middelburg
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Lake Chrissie
Transvaal
High Veldt
Swaziland
Portuguese Possessions
Delagoa Bay
Orange Free State
Vaal River
Komati R.
Geological Map of the area between Klerksdorp and the De-Kaap Valley showing the relation of the Gold-Fields to each other and to the High-Level Coal-Field of the Transvaal, by W. H. Penning, F.G.S.
Scale of English Miles.
27°
28°
29°
30°
31°
32°
33°
25°
26°
27°

folded and necessarily altered to an enormous extent. Regarding the fossils in the coal-bearing Upper-Karoo series, the ferns were not those of the Carboniferous age; and the Lepidodendroid fossil now exhibited by a Fellow of the Society probably came from the outcrop of some older rocks near that of the Upper-Karoo beds. The fossil fishes obtained by G. W. Stow and others from these beds have been described as related to Triassic forms.

Mr. Smith Woodward recognized the fish in Mr. Penning's photograph as *Semionotus capensis*, described in the Society's Journal, vol. xliv. p. 138. Among associated fish-remains *Cleithrolepis* also occurs. If such evidence be of any stratigraphical value, the Upper Karoo is homotaxial with the lower fish-bearing deposit of the Hawkesbury-Wianamatta Series in New South Wales (Gosford), and it probably represents some European horizon between the Upper Trias and Lower Lias.

Dr. Blanford had repeatedly noticed the resemblance between the geology of India and that of South Africa. He compared our present knowledge of South-African geology with that of the Indian Peninsula before local observations were connected by a general Geological Survey. In India it had been found that the rocks associated with coal-bearing strata formed an enormous system, ranging from Upper Palæozoic to Upper Mesozoic. The same might be the case in South Africa. The age of a South-African bed should not, he thought, be too precisely defined on account of the occurrence of a particular genus of fish. He was interested to hear Mr. Penning's testimony in favour of the glacial origin of the bed underlying the coal-bearing formation.

## 26. RESULTS *of an* EXAMINATION *of the* CRYSTALLINE ROCKS *of the* LIZARD DISTRICT. By Professor T. G. BONNEY, D.Sc., LL.D., F.R.S., V.P.G.S., and Major-General C. A. M^cMAHON, F.G.S. (Read April 22, 1891.)

[PLATE XVI.]

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### I. INTRODUCTORY.

GEOLOGISTS during the last decade have devoted much more attention to the rocks of the Lizard than in previous years. At the same time the effects of pressure as an agent of metamorphism, especially in producing foliation and simulating stratification, have become increasingly appreciated. Hence it is not surprising that the correctness of the view advocated by Prof. Bonney in 1883 *, viz., that the crystalline schists of the Lizard were in the main of sedimentary origin, has been contested, some writers even going so far as to express doubts whether the relation of these masses to the serpentine, gabbro, and other rocks of igneous origin had been correctly understood.

The results of work in other regions had raised suspicions in the author's own mind as to the trustworthiness of some of the data on which his inductions had been founded, and after spending several days in 1886 at the Lizard with Mr. Teall, who was more disposed than himself to regard pressure as a potent agent of metamorphism, he felt convinced that his earlier views would have to be modified, though to what extent could only be determined by further study of the district and by comparison with other regions.

In 1889 a paper was read before this Society by Gen. M^cMahon, in which the igneous origin of many of the foliated crystalline rocks was maintained, and an hypothesis put forward to

* Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 1.

explain, in certain cases, the banded arrangement of the constituent minerals *.

In the summer of 1890 the authors of the present paper met at the Lizard in order to discuss the whole question on the spot. They hoped by this means to bear united testimony as to the facts of nature and to avoid many opportunities for misunderstanding, while any diversity of opinion as to the interpretation of the former could be easily expressed. They were joined by the Rev. Edwin Hill, to whom they are indebted for constant help in field-work and in discussion, both by suggestions and by criticism. They believe that they may add his name as a witness to the facts recorded in this paper, and do not expect to find any serious difference of opinion on his part as to the main questions of interpretation.

During a fortnight's stay at the Lizard, followed by about four days at St. Keverne, they examined *de novo* almost all the more important coast-sections of the Lizard peninsula as far north as Mullion Cove on the west and the Nare Head on the east †. They had also the great advantage of going over some of the most critical sections with Mr. Teall, to whose views reference has already been made, and with Mr. Fox, to whose acute observation and conscientious work in this district geologists are so greatly indebted. The hours spent in frank interchange of opinion and in friendly discussion of views, sometimes divergent, were no less pleasant than profitable, for, in more than one instance, they removed misconceptions and demonstrated that the shield, if gold on one side, was silver on the other.

## II. The Serpentine.

In regard to the serpentine, the majority of competent observers are in general agreement. Hence it may be convenient to consider this rock first in order and use it as a kind of datum-line for the other rocks of the district, which will then be found to fall into two rather distinct classes. In dealing with the serpentine three subjects call for special attention:—(1) its origin and composition; (2) its relation to the rocks of earlier date; (3) the significance of its structures, if any.

(1) *Origin and Composition.*—These subjects have been so fully discussed by Prof. Bonney in his two papers and by Mr. Teall in his "British Petrography" that little more need be said. But, for convenience of reference, we have exhibited in tabular form the constituent minerals (other than serpentine) of the rocks noticed by these authors, to which have been added one or two varieties hitherto undescribed. The derivation of serpentines which exhibit

* Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 519.

† Want of time prevented them from examining the cliffs for about a mile on either side of the Blackhead. These are rather difficult of access, and consist, according to the Survey map, of serpentine, so that they did not seem likely to throw additional light on any question except those on which the authors were already satisfied.

characteristics similar to those of the Lizard from some variety of peridotite may now be regarded as demonstrated to the satisfaction of all petrologists who have studied the rock in the field and with the microscope. It is of course true that other magnesian silicates, such as rhombic and some monoclinic pyroxenes, can produce serpentine; but the correspondence between rocks thus originated and those of which the Lizard serpentine is a type, if it exist in certain rare cases, is almost exclusively in chemical composition and is associated with marked diversity in other respects.

The Lizard serpentines can be roughly separated into two groups: in the one a foliated mineral of the enstatite group is a conspicuous accessory; in the other a colourless augite or hornblende, usually the latter. A few are non-porphyritic, and in some cases exhibit no certain traces of any pyroxenic mineral, rhombic or monoclinic, though of course a spinellid or some iron oxide is always to be detected, and in one instance (at the Rill, W. of Kynance Cove) the presence of a fair proportion of felspar has been asserted.

Of the tables annexed, one gives the mineral, the other the chemical composition of certain varieties of the serpentine. Chrysotile is almost always present as well as ordinary serpentine, so it has been thought needless to enumerate these separately. The more or less foliated enstatite (bronzite) is also more or less serpentinized; in most cases, if not all, it is probably bastite, as has been demonstrated by Mr. Teall *. The hornblende (except when specified) is a white variety; the iron oxide is generally magnetite, but in the red serpentines much hematite is present. The term "spinellid" includes all varieties, from those which are a very deep brown (barely translucent), probably chromite, to the translucent rich brown grains (picotite) present in several specimens †. Under the head "chlorite" is placed a colourless mica-like mineral, resembling that described by Herr Weigand ‡. In some cases the included opacite suggests that it may be a bleached biotite. The figures within brackets in the column headed "Remarks" indicate the number of specimens on which the result is founded. The localities are arranged in order, beginning at the south end of the east coast and going round from the north to the west coast, which is followed southwards.

The annexed table of analyses contains, we believe, all that have been published, with four others, which, by the kindness of Prof. W. Ramsay, F.R.S., have been made in the chemical laboratory at University College (London). For these the authors are indebted to Mr. M. W. Travers, to whom they tender their best thanks. Numbers I.–V. doubtless represent varieties of the serpentine with conspicuous crystals of enstatite (bastite), chiefly used for ornamental purposes; VI.–IX. are from varieties of the Porthalla serpentine; X., XI. are varieties of the dull-coloured compact

* 'Brit. Petrogr.' p. 88.

† See also 'Picotite in Serpentine,' H. Fox, Trans. Royal Geol. Soc. Cornwall, vol. xi. pt. 5 (1891) p. 336.

‡ Quoted by Mr. Teall, 'Brit. Petrogr.' p. 112.

[*To face* p. 466.

| IX. | X. | XI. | XII. | XIII. |
|---|---|---|---|---|
| 43·35 | 41·43 | 42·89 | 40·29 | 58·90 |
| 4·08 | 7·29 | 0·76 | 5·10 | 3·99 |
| | 7·87 | 6·30 | 4·94 | 2·32 |

| | I. | II. | III. | IV. | V. | VI. | VII. | VIII. | IX. | X. | XI. | XII. | XIII. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 38·86 | 38·58 | 40·40 | 38·29 | 38·50 | 38·60 | 37·15 | 39·50 | 43·35 | 41·43 | 42·89 | 40·29 | 58·90 |
| $Al_2O_3$ | 2·95 | 3·06 | 0·65 | ........ | 1·02 | 0·10 | 5·60 | 5·08 | 4·08 | 7·29 | 0·76 | 5·10 | 3·99 |
| $Cr_2O_3$ | 0·08 | 0·08 | | | | | | | | | | | |
| $Fe_2O_3$ | 1·86 | 1·95 | ......... | ......... | 4·66 | 11·55 | 1·10 | 8·12 | 10·74 | 7·87 | 6·30 | 4·94 | 2·32 |
| $FeO$ | 5·04 | 5·10 | 7·47 | 13·50 | 3·31 | | 8·80 | | | 0·87 | 3·83 | 3·98 | 3·76 |
| $NiO$ | 0·28 | 0·30 | 0·15 | ......... | 0·59 | | | | | | | | |
| $CaO$ | trace | trace | ......... | ......... | 1·97 | trace | 0·10 | trace | 1·51 | 1·88 | ......... | 11·85 | |
| $MgO$ | 34·61 | 34·32 | 37·43 | 34·24 | 36·40 | 33·62 | 32·80 | 34·65 | 28·43 | 32·73 | 38·09 | 25·67 | 26·80 |
| $MnO$ | trace | trace | | | | | | | | | | | |
| $FeS_2$ | ......... | ......... | ......... | ......... | 0·41 | | | | | | | | |
| $Na_2O$ | 0·77 | 0·76 | ......... | ......... | ......... | 3·31 | | | | | | | |
| $K_2O$ | 0·33 | 0·30 | ......... | ......... | ......... | | 0·29 | 0·10 | 1·35 | | | | |
| $H_2O$ lost on ignition | 15·52 | 15·52 | 13·90 | 12·09 | 12·35 | 12·82 | 13·70 | 12·00 | 8·69 | 7·93 | 7·98 | 8·17 | 2·91 |
| $H_2O$ lost at 100° C. | | | | | | | 0·46 | 0·55 | 1·85 | | | | |
| Insoluble in HCl | ......... | ......... | ......... | ......... | 1·37 | | | | | | | | |
| Total | 100·30 | 99·97 | 100·00 | 98·12 | 100·58 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 99·85 | 100·00 | 98·68 |
| Sp. gr. | 2·59 | | ......... | ......... | 2·587 | 2·65 | 2·56 | 2·545 | 2·644 | 2·74 | 2·85 | 2·77 | ......... |

I. and II. Ornamental serpentine from the Lizard. Dark green to black, thickly spotted with red; enclosing imperfect crystals. [This analysis may be taken as representing a very common and characteristic variety of Lizard serpentine.] (Of the water, 2·06 was lost in the water bath.) Analysis by J. A. Phillips. Phil. Mag. 1871, (4) vol. xli. p. 101.

III. "Clouded reddish brown and greenish serpentine containing small grains of diallage" [bastite], said to be from the Lizard Point. [Probably from near Pen Voose.] The FeO includes also oxide of chromium. Analysis by T. S. Hunt. Am. Journ. Sci. vol. xxvi. (1858) p. 239.

IV. "The red, earthy sometimes semi-crystalline base of the serpentine porphyry of Kynance Cove." Analysis by S. Haughton. Phil. Mag. 1855, (4) vol. x. p. 254.

V. Matrix of black serpentine from near [*i. e.* to the north of] Cadgwith. Contains porphyritic crystals of bastite. The $SiO_2$ includes traces of $TiO_2$. The rock was dried at 100° C. The $H_2O$ includes traces of $CO_2$; and traces of sulphuric acid are also noted as present. Analysis by Mr. Hudleston, in Appendix to paper on serpentine of the Lizard district, by Prof. Bonney. Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 925.

VI. Greyish green granular serpentine. Porthalla.

VII. Dark oil-green serpentine. Porthalla.

VIII. Reddish brown granular serpentine. Porthalla.

IX. Dull dark red serpentine. Porthalla. [This, I think, must be rather an abnormal specimen, for evidently it is almost a picrite.—T. G. B.]

(VI.–IX.) The $SiO_2$ includes also insoluble residue. The alkalies include also loss. Analyses by Mr. Collins. Quart. Journ. Geol. Soc. vol. xl. (1884) p. 467.

X. The Rill. Supposed to contain felspar. See Geol. Mag. (1887) pp. 69, 137, 380. By Mr. M. W. Travers, of University College, London. A partial analysis is given in Geol. Mag. (1887) p. 380.

XI. Gew Graze. Red serpentine, minutely granular in texture. Described in Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 918. By the same.

XII. Quarry near Lower Predannack. Reddish serpentine with numerous crystals of white hornblende. [Almost a picrite, though I have never seen any felspar.—T. G. B.] Described in Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 918, and vol. xxxix. (1883) p. 23. By the same.

XIII. From a weathered portion of the same hand-specimen. By the same.

Analyses of Soapstones by S. Haughton. (Phil. Mag. 1855, (4) vol. x. p. 255.)

| | $SiO_2$ | $Al_2O_3$ | MgO | $H_2O$ | Total. |
|---|---|---|---|---|---|
| From the vein at Kynance | 42·47 | 6·65 | 28·83 | 19·37 | 97·32 |
| From the vein at Gew Graze | 42·10 | 7·67 | 30·57 | 18·46 | 98·80 |

| Localities. | Olivine. | Enstatite. | Augite. | Hornblende. | Chlorite. | Iron Oxides. | Spinellids. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| Balk Quarry | ... | * | ... | ... | ? | * | ? | Red (2). |
| Cadgwith (above Frying Pan) | * | ... | ... | * | ... | * | * | Red. |
| do. , Quarry N. of | ... | * | ... | * | ... | * | * | Red. |
| Enys Head, near | * | * | ? | * | ? | * | * | Black, abundant in this district (2). |
| Kennack Cove | ... | * | ... | ... | ... | * | * | Black, calcite or magnesite in veins. |
| Carn Spernic (quarry W. of) | * | * | * | ... | ? | * | * | Red (3). |
| do. shore beneath the same | ... | * | ... | ... | ... | * | ? | Red (3, two normal, one more compact). |
| Lankidden Cove | ... | * | ... | ... | ... | * | ? | Greenish-purple (3, one rather streaky, one with veins as above). |
| Coverack (by road above village) | * | * | * | .. | ... | * | * | Red. |
| do. in Cove | * | * | * | ... | ... | * | ... | Red (3, two normal, one more compact). |
| do. Quarry W. of village | ... | ? | ... | ... | ... | * | * | Dark, much disseminated opacite, ? affected by contact. |
| Polkerris | ... | ? | ... | ... | ... | * | * | Reddish. |
| Porthalla (quarry by path) | ... | ... | ... | ... | ? | * | * | Greenish-purplish. |
| do. shore (ordinary) | ... | ? | ... | * | * | * | ... | Id. |
| do. do. (at contact) | ... | ... | ... | * | ... | * | ... | Id., approaches Mullion type, but more compact. |
| do. do. (streaky) | ... | ? | ... | * | * | * | ... | Id., colours more separated. } 10 specimens. |
| do. do. (banded) | ... | ... | ... | * | * | * | ... | Id., colours in bands. } |
| Goonhilly Downs Quarry ... }<br>do. do. do. }<br>Helston-Coverack road ... } | * | * | * | * | ... | * | * | Streaky, reddish—a brown hornblende. |
| Helston-Lizard road (first outcrop). | ? | ? | ? | * | ... | * | * | Dark, much white hornblende, a little brown. |
| Mullion Cove | * | ... | ... | * | ... | * | * | Nearly black, much white hornblende (2). |
| Lower Predannack Quarry | * | ? | ... | * | * | * | * | Reddish, much white hornblende (4). |
| Ogo-dour Cove (near junction) | ... | ... | ... | ... | ... | * | * | Black, rather compact, streaky, much chrysotile. |
| George's Cove | * | * | ... | * | ... | * | * | Striped, dark purple-grey, and light greenish-grey; (3), sphene in one specimen. |
| Gew Graze | * | ? | * | * | ... | * | * | Reddish, a little brown hornblende; (?) trace of felspar. |
| The Rill | * | * | * | * | ? | * | .. | Dark, white spots; felspar or chloritoid (?). |
| Lawarnick Pit (W.N.W. of Kynance). | * | * | ... | * | * | * | ... | Rather dark; some of the chlorite is probably a bleached biotite. |
| Kynance Cove | ... | * | ... | ... | ... | * | * | Striped reddish-brown and light greenish-grey. |
| do. (dyke N. of "the Steeple"). | ... | ... | ... | ... | ... | * | ... | Red, compact; ? fluxion structure. |
| Holestrow | ... | ... | ... | ... | ... | * | ... | Greenish-grey, rather decomposed, veined with steatitic minerals. |
| Pentreath Beach | ... | ... | ... | ... | ... | * | ... | Calcite or magnesite veins. |

serpentine more common on parts of the west coast and on the north; while XII. is a variety almost confined to the west coast, rich in small crystals of colourless hornblende; XIII. is from a weathered portion of the same specimen as XII. It was made by

reason of a misunderstanding, but the difference is so remarkable that it seemed worthy of preservation, if only to indicate the caution which must be exercised in selecting a sample for analysis.

(2) *Relation to the older Rocks.*—The serpentine of the Lizard district, as stated by Prof. Bonney, is associated with the subdivisions of the crystalline schists which were named by him the Granulitic Group and the Hornblendic Group, but it has not yet been detected among either his Micaceous Group, or the gneisses of very ancient aspect which were discovered by Mr. Fox in the islands fringing the south coast *.

It will suffice for the present to say that both the Granulitic and the Hornblendic Group exhibit marked structural characteristics. In the former a dark dioritic rock is sometimes veined, sometimes banded, by one of lighter colour, which often closely resembles a granite; the latter is very frequently so regularly banded as to suggest an original stratification. Whatever be the significance of these structures—a question which we reserve for the moment—neither rock, in its present state, can be the result of a single operation.

It has indeed been suggested that all the rocks of the Lizard district are the result of some sort of segregation from one magma †. We do not propose to treat this hypothesis seriously; but there are three other hypotheses which call for discussion, and these appear to cover the field: that (*a*) the serpentine (with some of the later rocks) and the older series form an igneous complex which has been afterwards profoundly affected by earth-movements—as if a heterogeneous mass had been passed between a pair of rollers; (*b*) the serpentine is really intrusive in the older series, but the relations of the rocks have been so far masked by subsequent earth-movements as to obliterate any conclusive evidence of the intrusion; (*c*) the serpentine (as maintained by Prof. Bonney from the first) is intrusive in the older series, and the amount of subsequent disturbance has not sufficed in most places materially to disturb their relations.

Along the eastern coast many sections can be found which exhibit the serpentine and the rocks of the Granulitic Group in intimate association, from Compass Cove to Polbream Point, also about the Frying Pan, and again from the north side of Polbarrow to the Balk. We do not deny that occasional sections may be found in which the present relations of the two are the result of faulting, or which, did they stand alone, might seem to support the view that the granulitic rock was intrusive in the serpentine; but, after again examining all the sections on both coasts described by Prof. Bonney in 1877, we have not the slightest doubt that the serpentine is intrusive in the granulitic rock, which was, at that time, substantially in its present condition, and that, as a rule, their relations have not been disturbed subsequently to any noteworthy extent. The serpentine has broken through the granulitic rock, some-

* Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 309.
† Geol. Mag. (1888) p. 554, (1890) p. 505.

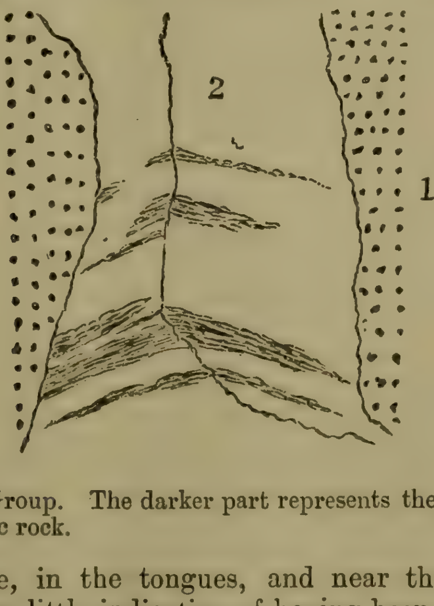
times apparently twisting up the ragged ends into dyke-like masses, sometimes perhaps breaking off and carrying up huge fragments. Here a dyke of serpentine parts two masses of granulitic rock, the outer margins of each being in contact with serpentine, which continues for some distance; there a tongue of serpentine is forced like a wedge into a banded mass of the granulitic rock, or is protruded between two of the layers. Here, in a similar mass, the bands are nipped up or cut off obliquely by the serpentine (fig. 1); there, in

Fig. 1.—*Section in Quarry near Kildown Point.*


1. Serpentine.
2. Reddish granitoid rock, with dark bands (Granulitic Group).

one of less regular structure, the granitic veins may be seen to run up to the serpentine, and be, as it were, cut off by it (fig. 2). So far as structure goes, the relations of the Granulitic Group and the serpentine are identical with those which are exhibited by banded gneisses or schists, and granites intrusive into them.

Fig. 2.—*Section near Cavouga Rocks.*




1. Serpentine.
2. Granulitic Group. The darker part represents the dioritic, the lighter the granitic rock.

The serpentine, in the tongues, and near the granulitic rock generally, exhibits little indication of having been crushed: though now and then a faint resemblance to a foliation—recalling to some

extent a fluidal structure—may be detected. The rock, however, is usually rather rotten; very commonly there is a dusty-looking, pale-coloured, more or less chrysotilic layer between the two rocks, which is continuous with the serpentine, but does not adhere to the granulitic mass. Indeed we have never found the two rocks actually welded. Signs of crushing and slickensides may no doubt be not unfrequently seen at junctions. This is only to be expected, because the tenacity of the two rocks is so different that, even if welded, they would have parted here under strains from ordinary earth-movements. The serpentine also at the margins is often decomposed, and its structure is obscured by secondary chrysotile, steatite, and other like minerals. The serpentine, which seems to include these gneissoid masses, sometimes exhibits a slight streakiness, the significance of which will be considered presently. Sometimes this may be parallel to the apparent bedding of the granulitic rock, but at others the two structures are almost at right angles, so that evidently they are not necessarily connected.

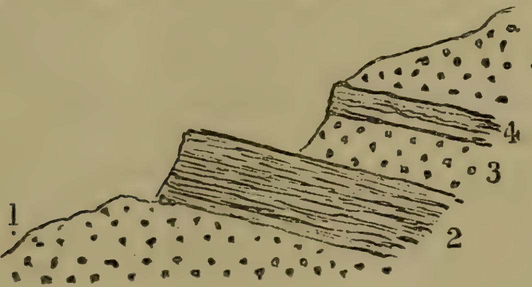
The relations of the serpentine to the hornblende-schist differ somewhat from those with the Granulitic Group. Masses of the latter, apparently included in or pierced by the serpentine, may be found by scores; with only one or two slight intervals, they literally fringe the eastern coast for a distance of three miles, measured along its curve, and they are not unknown, though much less common, on the western coast *. But the Hornblendic Group is not often seen actually cut by or entangled with the serpentine. This, however, may also be said in regard to the other intrusions. Dykes of any kind, so far as we know, are not very common in it. Still, though the serpentine and hornblende-schist in some cases may be faulted together, the relations in a few are clear. At Henscath, just north of Mullion Cove, we find it impossible to explain by earth-movements, or by any theory but that of intrusion, the position of the apparently insulated mass of serpentine on the little headland, and the two rocks, in at least one case, are still welded together. Again, the same holds good in regard to the junction exposed in the upper rocks near Parc Bean Cove (north of Ogo-dour Cove †). Strips of the hornblende-schist, regularly banded, are split off by or included in the serpentine, and the two rocks in more than one place are welded together, though the rottenness of the latter makes it impossible to detach and bring away specimens exhibiting the junction. Moreover, the hornblende-schist, thus included, exhibits

* The masses at Kynance Cove, mentioned in my paper, Quart. Journ. Geol. Soc. vol. xxxiii. (1877) pp. 884–928, certainly in some cases, and perhaps in all, are better referred to the Granulitic than to the Hornblendic Group. The road descending to the cove (p. 888) crosses a mass which, when less clearly exposed, was mistaken for a granite vein. There are other characteristic masses along the shore N. of Pentreath beach; some of these are mentioned as hornblende-schist in the above paper, in which no division of the schists is attempted; they were not again examined for the purpose of writing the second paper, the precise reference of every block being unimportant.—T. G. B.

† Bonney, Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 22 (referred to as being 'to the north of Ugethawr').

some peculiarities *, which we consider to be the result of contact-metamorphism. Again, in a little pit on Carnbarrow, at the top of the cliffs, a "slabby" piece of banded hornblende-schist, about 8 inches thick, is completely surrounded by serpentine. Lastly, there are the junctions at Porthalla, which must be described in rather more detail, as Prof. Bonney's interpretation has been questioned in the pages of this Journal by Mr. J. H. Collins †, who maintains that there is a gradual transition from the hornblende-schist to the serpentine, the latter being regularly interbanded or interstratified with the former. We find, instead of the orderly arrangement depicted in his published section ‡, that a mass of serpentine breaks through the hornblende-schist, and runs diagonally, roughly in a westerly direction, up the craggy face of the hill §. Above it is a great mass of hornblende-schist, generally with little banding or foliation, and thus dioritic in character. At a short distance below it are exposed the rather fissile schists referred by Prof. Bonney to the Micaceous Group, the intervening space being concealed by débris. But in three or four places on the rocky shore, between tide-marks, or just above high water, the relations of the serpentine and schist are well displayed. For instance, rather on the western side of the serpentine, slabs of banded hornblende-schist occur in that rock, the lower about three feet thick, the upper about one foot; the intervening space, rather more than two feet thick, being occupied by serpentine ‖ (fig. 3).

Fig. 3.—*Section at the foot of the cliffs, Porthalla.*




1. Serpentine.
2. Hornblende-schist, about 3 ft.
3. Serpentine, about 2½ ft.
4. Hornblende-schist, about 1¼ ft.
5. Serpentine.

* See below, p. 473.

† Quart. Journ. Geol. Soc. vol. xl. (1884) p. 458; Geol. Mag. (1885) p. 298, and (1886) p. 359.

‡ Quart. Journ. Geol. Soc. vol. xl. (1884) p. 461, fig. 2.

§ Since the publication of Mr. Collins's paper, I have been thrice at Porthalla. On one occasion I had with me a copy of Mr. Collins's published section, and we sought to reconcile it with what we saw. After using our best endeavours, we were obliged to abandon the task as hopeless. Gen. McMahon had also visited Porthalla in 1887, and had met with no better success. The junction of the serpentine and hornblende-schist, which I saw in a quarry in 1882, had disappeared by 1886, and cannot now be found.—T. G. B.

‖ Observed and drawn in 1886.—T. G. B.

These intercalated pieces of schist cannot be traced far. Again, near the eastern side of the serpentine, apparently enclosed in it, a mass of regularly "bedded" hornblende-schist * may be seen at the foot of the cliff. This is split by a wedge-like mass of serpentine, which narrows down to less than a foot across, on the western side of which comes a single "bed" of schist about 5 inches thick. Next comes a sheet of serpentine of about the same thickness, followed by another block of hornblende-schist. In this, if we mistake not, may be seen the end of another wedge of serpentine, coming in the opposite direction to the former †. Again, with regard to the asserted production of the serpentine from a stratified rock, bearing more relation to the hornblende-schist than to a peridotite, by some kind of transmutation not easy to understand, Mr. Collins's own analyses ‡ indicate that the serpentine varies from a perfectly normal example of an altered peridotite to one which exhibits some approach to the picrites §, a variation which is far from rare.

It is true that near the junctions the serpentine sometimes becomes streaky or even somewhat banded in structure; the hornblende-schist also departs a little from the normal type, as at some other junctions, and is covered with a thin film of a steatitic mineral. Thus the two rocks occasionally so closely resemble one another that by the unaided eye alone they can hardly be distinguished; the difference is, however, quickly perceived by continued scratching with a knife, or by a few blows with the hammer, and is obvious on microscopic examination. In other cases, however, the two rocks are so clearly distinguished that the point of a knife may be placed on their junction-plane; while the changes in the hornblende-schist, which we pause for a moment to describe, are suggestive here, as elsewhere, of contact-metamorphism.

The hornblende-schist, in the localities where we examined it in contact with the serpentine, is considerably altered. Macroscopically, it assumes a rather grey and slightly "dusty" aspect: microscopically, it exhibits marked changes. We have examined slices from specimens obtained in three localities.

(1) Specimen in contact with serpentine at Porthalla. This rock exhibits a banded structure, and consists mainly of a colourless micaceous mineral, the flakes varying in size in different bands, which, with crossed nicols, gives low tints (white to milky grey) and straight extinction, and of hornblende, which, in form and structure, either resembles the last-named mineral or is somewhat acicular, the hue varying from a pale brown to almost colourless. The

* The 'beds' are almost vertical, and strike between W.N.W. and N.W.

† The serpentine is rather rotten; the section is, in places, obscured by shingle, &c.; and part of the hornblende-schist is stained of a reddish colour, so that it resembles the serpentine. The mass of the former on the one side of the first 'wedge' cannot exceed about four yards, and on the other about three from this distance brings us again to serpentine.

‡ See tables of analyses, facing p. 466.

§ The term is used, not for a variety of the true peridotites, but for one in which some felspar is commonly present.

former mineral is probably a chlorite, similar to that described by Herr Weigand.

(2) From the intrusive junction in Parc Bean Cove (2 specimens): one, " 2 or 3 inches from contact-surface," consists of roundish or rather oblong grains of pale-brown hornblende and colourless augite in a minutely granular matrix; this is composed of a filmy brownish mineral, resembling the hornblende, and a colourless one (? felspar), together with some scattered granules of brownish iron-oxide. Some transverse cracks are filled by secondary minerals, in part a flaky hornblende. The other specimen, " from a slab about 8 inches thick, enclosed in serpentine," is very like that from Porthalla, except that two or three bands in it are chiefly occupied by a dull green chlorite, which in places is iron-stained, and is associated with grains of magnetite; also one or two grains of decomposed felspar can be detected.

(3) From a piece about the same thickness, similarly enclosed, from the pit above Carnbarrow. This, to some extent, combines in one specimen bands which respectively resemble parts of each of the above, but other bands are characterized by a fair amount of decomposing felspar, and thus in structure it more closely resembles the normal rock.

In two of these the above-mentioned mineral changes might possibly be set down to ordinary decomposition, though we do not so interpret it; but this could hardly be asserted in the first and last specimens. The alterations, especially in the hornblende, so far as our experience goes, resemble those which have been produced in " greenstones " by contact-metamorphism. In each case, as it happens, the hornblende-schist is a well-banded variety.

Mr. Collins states that " the massive serpentine of Porthalla does not present that reticulated structure which has been regarded as the result of the alteration of olivine rocks " *. Either he must have examined a very small number of specimens and been singularly unfortunate in collecting them, or have had a limited experience in the structure of altered peridotites. It is quite true that there are differences between this rock and the serpentine at Coverack or farther to the south; the latter contains more bastite, and as it was once rather coarsely crystalline, the characteristic reticulated structure can be seen at a glance. The Porthalla rock, however, was evidently at the first a fine-grained peridotite †, but, making allowance for this, it presents no difficulties to an experienced eye. Occasionally the structure is as characteristic, though on a scale of about $\frac{1}{2}$, as in the normal rock to the south. In some parts, where the banding is most marked, there is considerably more variation in the mineral constituents; a white micaceous mineral in small flakes is occasionally rather abundant—possibly the variety of chlorite investigated by Herr Weigand in the Rauenthal serpentine—larger flakes of this are sometimes associated in nests, with grains of mag-

* Geol. Mag. (1885) p. 300.

† Probably very like that from St. Paul's Island, described by Prof. Renard.

netite, or lie nearly parallel (with inclusions of the latter) so as to suggest the bleaching of a biotite *. Occasionally the remains of a pyroxenic constituent can be detected; sometimes it is probably an enstatite, but sometimes the oblique extinction of a remnant suggests a colourless hornblende. In some cases a considerable quantity of a semi-transparent mineral is present in minute granules, occasionally aggregated, which suggests the presence of an alumina-silicate. The banding is seen to be caused by the variation in the amount of this mineral, the opacite, and the chlorite. The most strongly banded variety, as we believe, is rather rare †. The structure in both is better seen in slightly weathered specimens than on freshly broken surfaces.

No sign of crushing can be discerned in these specimens. Both the variety with thin streaky lines and little rounded eyes of a mica-like mineral, and that with distinct bands of different colour and texture ‡, present macroscopically a very close resemblance to the fluxion-structure of a felstone or a rhyolitic rock. A very fine specimen exhibiting this structure (which is much more conspicuous on slightly weathered surfaces) is figured on Plate XVI.

The microscopic examination of thin slices shows that the apparent foliation is due to the streaky condition of the parent rock prior to its serpentinization—differences in the original composition of the streaks being now represented by slight mineral and structural differences in the resulting serpentine. In the opinion of the authors, the structure can only be explained as a fluxion-structure; that is to say, as being the result of traction acting on either an imperfectly blended mixture of two magmas, differing slightly from each other in composition, specific gravity, or fluidity, as in the case of a banded felsite or rhyolite, or on a mass, in which complete crystallization had been arrested by subsequent motion at a time when only a portion of the constituent minerals had separated themselves out from the magma.

The eruptive character of the serpentine (peridotite), which has been described above, as well as the microscopic evidence, shows conclusively that the original rock cannot have had a sedimentary origin.

(3) *The Structures of the Serpentine.*—A somewhat similar structure is exhibited by the serpentine in other parts of the Lizard district. Along the western coast this rock very commonly exhibits some approach to mineral banding. For instance, at Mullion sometimes, and rather more markedly at Lower Predannack, the crystals of colourless hornblende tend to lie parallel. But, on microscopic examination, we cannot discover that the constituent minerals exhibit any indication of having either been crushed or suffered any mechanical disturbance which cannot be explained

* As in the scyelite of Caithness, Judd, Quart. Journ. Geol. Soc. vol. xl. (1884) p. 406.

† One specimen, picked up on the shore by Prof. Bonney, suggests the possibility of the one variety being intrusive in the other (see Plate XVI. at the line AB).

‡ They are sometimes ⅛″ wide.

by slight strains, either in cooling or in the alteration of the olivine constituent into serpentine. At Lawarnick Pit, near Kynance Cove, a faint banding is often perceptible in the compact serpentine, and a like structure is often developed rather conspicuously on the weathered surfaces of the rock, both in the neighbourhood inland and for some distance along the coast to the north. This structure commonly has a roughly uniform strike, and thus might naturally be interpreted as a result of pressure; but we noted variations in this district from a little W. of N., round by W. to W.S.W. The rock also is not rendered fissile by it. So, if a pressure structure, it is certainly anterior to serpentinization.

On the east coast this structure is much more rare and local. It may not seldom be detected on slightly weathered surfaces in the black serpentine S. of Kennack Cove, but the rock under the microscope does not give any indication of having suffered from a general crushing. Near Compass Cove we observed a sheet of compact-looking serpentine, from 4″ to 8″ across, in the ordinary serpentine; the latter being one of the usual red serpentines with fairly conspicuous but rather altered bastite-grains. This mineral also occurs in the former, but much more sparsely (being sometimes absent), and in grains less than half the diameter of the other. The compact rock under the microscope does not, however, show any sign of crushing, and presents the usual structures; indeed, the presence or absence of bastite is the main difference between the two slides.

On the E. side of Lankidden Cove, a rather compact serpentine exhibits grains of an iron oxide arranged in lines rudely parallel, and in the middle is a band about 4″ wide, with a slightly streaky structure, containing bastite; the dominant colour in both being a greenish grey. Neither the grains of iron oxide, probably chromite, nor of bastite, in the latter, show any signs of crushing. The former indicates, by the parallelism of the "strings" of opacite, and the arrangement of the "rootlets" of flaky serpentine, that there has been originally a somewhat parallel arrangement of the olivine grains, but the resemblance is far greater to a fluxion- than to a crush-structure. A similar structure was noted in a second locality, but the serpentine generally is normal.

The following extract from Prof. Bonney's diary, describing a visit to the lherzolite of the Lac de Lherz, written in 1876 (June 27th), indicates the existence of a similar structure in a peridotite, which certainly appears quite free from the effects of dynamo-metamorphism:—"Occasionally also a sort of stratified appearance comes out in weathering, just as I have observed in some of the Lizard serpentines. I could not see that this corresponded with any marked internal structure." He states, in regard to this, in his account of his visit printed in the 'Geological Magazine' for Feb. 1877 *, that the structure, in his opinion, has, like that at the Lizard, "some connexion with an internal parallelism," and thinks "it will prove to be connected with a fluidal structure."

* Dec. ii. vol. iv. p. 60.

A structure which would certainly leave its mark, and probably produce a serpentine, such as some of those mentioned above, is described and figured by Prof. Renard in his description of the peridotite of St. Paul's Island *. The rock is rather fine-grained and contains "eyes" of enstatite. The author, by an admirable piece of inductive reasoning, proves that the rock exhibits a fluxion structure and is of igneous origin, but abstains from accepting the conclusion because it has been asserted by certain authorities that some peridotites are metamorphosed stratified rocks.

## III. The Rocks older than the Serpentine.

These were divided by Prof. Bonney, in 1882, into three groups, between which, however, no sharp line of demarcation was supposed to exist. Of these he considered the Granulitic to be the upper, the Hornblendic the middle, and the Micaceous the lower. He thought the series, as a whole, had been sedimentary in origin, but that the hornblendic rocks were probably altered tuffs, and, in some cases, might even have been basic lavas. In 1888, Mr. Fox † communicated to the Society the results of his examination of the islands fringing the south coast of the Lizard, together with petrographic notes by Mr. Teall; this was followed in 1889 ‡ by a paper from General McMahon on the granulitic and hornblendic rocks. It will, therefore, suffice on the present occasion to refer for details to these and other papers, and indicate in general terms the problems which are presented for solution.

### (1) *The Granulitic Group.*

This group, as has been said, is characterized by a dark dioritic rock, veined or interbanded by a lighter one, which resembles a rather fine-grained granite. The former is not seldom porphyritic, the structure setting in and disappearing in an irregular way, so that a mass is "spattered" with felspar crystals, as is the face of a rock by the marks of a charge of shot. A slight foliation can often be discerned in the groundmass. Porphyritic felspar, as we now know, makes an igneous origin at least probable; but the matrix (which consists mainly of rather rounded or slightly elongated grains of felspar and hornblende, with more or less biotite §), so far as we are aware, has not disclosed any characteristic structure. The lighter rock is very closely allied to a vein-granite. The felspars are not idiomorphic, but occur, like the quartz, in rather rounded or elongated grains. The history of the rock, so far as regards its macroscopic character, can be best studied in Kennack and in Pen Voose Coves. It will suffice to recapitulate the principal facts of which any theory as to the origin of the group must take account.

* 'Challenger' Reports, Narrative, vol. ii.
† Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 309.
‡ *Ibid.* vol. xlv. (1889) p. 519.
§ Apatite, sphene, and magnetite are present in nearly all slices.

(1) In some cases the dioritic rock is pierced by veins of the granitic, which may be of any thickness from a few inches to a few lines; occasionally the former is completely brecciated and the pieces are separated by the latter rock, the intervals also varying in thickness in like way. Thus in the Granulitic Group we find sections which closely resemble those where an igneous rock breaks up and includes another igneous * or a massive sedimentary rock.

(2) In other cases the two varieties, for considerable distances, appear perfectly interstratified, and exhibit regular bands of the one or the other which vary in thickness from several inches to a small fraction of an inch, with occasional layers of a rather intermediate character †. In the latter case the lines of junction, though fairly sharp, do not resemble ordinary intrusive junctions—there are no indications that the one rock has been broken by the other. The structures of the two are similar, and the one seems to pass into the other by a very rapid mineral change.

(3) The thin slices under the microscope do not exhibit either that mixture of larger and smaller grains, or the peculiar minute "mosaic" structure, which commonly occur when a rock already crystalline has been crushed. The structure is not that characteristic either of the "newer gneiss" series of Glen Logan, or of one of the crushed granitoid rocks common in the Central Alps; though to these it occasionally presents a very faint resemblance. Nor is it that of the Saxon granulites. The present structure, whether original or secondary, seems to have been assumed *in situ*.

(4) Between the two extremes mentioned in (1) and (2), every intermediate form can be discovered. The angular dioritic fragments appear to be gradually flattened or elongated till they become lenticular streaks or even bands, and the vein-like intercalations of granite appear to be drawn out with them into similar bands, very much as a mixture of glass of two colours can be drawn out when it is heated until it becomes viscous.

These conditions appear to be best fulfilled by the following hypothesis :—that into a basic magma, which at any rate was sufficiently solid to break into fragments, an acid magma, at a very high temperature, was injected,—that either the more basic material was still somewhat plastic when this intrusion took place, or it was, by this accession of heated stuff ‡, so far softened that it was drawn out into streaks, and was even sometimes slightly mixed with the other by actual fusion, when movements occurred in the mass; and

* This, so far as my experience goes, is rather rare and local in its occurrence. The most remarkable instance which I have seen of the brecciation of one igneous rock by another was at the Corporation quarries, Montreal, where the nepheline syenite is shattered by and embedded in a rather compact dark rock, perhaps a tephrite.—T. G. B.

I have seen some striking illustrations of the complete brecciation of gneiss by granite in Spiti.—C. A. McM.

† This structure is rather more conspicuous in Pen Voose Cove; the former in Kennack Cove.

‡ Probably the temperature of solidification in the basic rock would be considerably lower than that of the acid rock.

that afterwards, as the temperature gradually fell, the whole mass became crystalline *. Thus the banded gneissoid rock of the Granulitic Group is an example of a kind of flow-structure on a large scale, wholly or (more probably) in part antecedent to crystallization. As this rock, in its distinctive characters, agrees with a large number of "banded gneisses," in which the ordinary symptoms of pressure-modification cannot be detected, and which appear to have at any rate completed their crystallization *in situ*, this hypothesis may prove to be of wide application. If, however, the bands do not differ very materially in their mineral composition—as is often the case with the banded Archæan gneisses—the hypothesis may assume a simpler form, and with them it may be only necessary to suppose that, as in the case of many rhyolites, some differentiation of constituents had been set up in the magma, the one part becoming slightly harder than the other, though still capable of being drawn out, so that the whole mass assumed a coarse fluidal structure, and subsequently, since its environment was widely different from that of a normal igneous rock, took on a holocrystalline, yet still a peculiar structure, different from that usually found in granites and diorites.

### (2) *The Hornblendic Group.*

That this group underlies the Granulitic, is, in most places, a probability rather than a certainty, the two commonly being separated by a fault or a mass of serpentine. But, assuming the Granulitic Group to occupy a definite horizon, its relations to the Hornblendic are suggested in more than one place, and are, we think, clear in the crags on the south side of Cadgwith Cove, where the latter rocks may be seen gradually rising up from beneath the former.

The Hornblendic Group exhibits structures curiously imitative, if not actually indicative, of stratification, certainly over a larger area and probably through a greater thickness than the Granulitic †. It includes fairly well banded schists almost everywhere from Porthalla to the Lighthouses on the one coast, and from Polurrian Cove to near Old Lizard Head on the other. Their structures have been described by the present authors, who have regarded them, though from somewhat different points of view, as indicative of stratification in the original materials.

This group has been again examined with considerable care. From the chemical analysis as well as the mineral composition it seems clear that its rocks must originally have been of igneous origin; the more massive may represent altered basaltic lavas, the more

* Probably it was a mixture of crystalline grains and half melted stuff rather than a true liquid, so that it was difficult for any mineral to assume an idiomorphic form. The larger porphyritic crystals in the diorite were probably anterior to the epoch mentioned above.

† The hornblende-schists are displayed, practically unbroken, in cliffs some 200 feet high, between points nearly a mile apart as the crow flies; the Granulitic Group, so far as we remember, seldom occurs without a break from top to bottom of such a cliff, or for more than a few dozen yards at most.

banded altered tuffs of similar composition. As regards the former, some of the "eyed" hornblende-schists mentioned by one of us, as for instance on the north side of Porthoustock Cove, may be a porphyritic dolerite which has been modified by pressure *, and converted into a slightly foliated epidiorite. Other masses again, as in the upper cliffs at Porthalla, are not at all banded and are even practically without foliation. It is, however, difficult to attribute the mineral banding and other structures in most parts of the mass to the crushing or shearing of a holocrystalline rock. Is it then to be explained as a kind of fluxion-structure, as we have already done in the case of the Granulitic Group? Some of the hornblende-schists present a very close structural resemblance to certain hornblendic bands in the latter group, and to some other rocks, hereafter to be mentioned, which are undoubtedly igneous. Moreover, the mineral banding—stripes consisting mainly of felspar or epidote alternating with those mainly of hornblende—as at Cadgwith or to the S. of Church Cove, would lend itself very well to this explanation. Indeed, where the bands attain a considerable thickness, it is not very easy to explain them by segregation during metamorphism †. One case, indeed, where the thickness of the bands is perhaps at a maximum for the district, seems to require the former explanation. A pit has recently been opened by the side of the road leading down to Mullion Cove. The rock excavated is partly a coarse saussurite-hornblende rock, without definite structure, partly a well-banded variety of the same, some of the bands being full ·3″ thick; the one clearly passes irregularly into the other. The former under the microscope presents considerable resemblance to one of the east-coast gabbros, for it affords the remains of plagioclase felspar, indications, and in one case at least a remnant, of diallage, and even a suggestion of the former presence of olivine. The banded variety contains the same minerals, and bears considerable resemblance to the *flaser*-gabbros described hereafter; its structure does not suggest crushing, and one or two of the thinner bands, where the two minerals are smaller in size, present a very close resemblance to an ophitic structure, in which there is a slight orientation in the felspars. We do not think it possible to explain this structure by the shearing of a coarse holocrystalline mass. At any rate the rock must originally have been a variety of gabbro ‡.

But in some members of the Hornblendic Group we have to explain, not only a banding, but also repeated resemblances to slightly irregular deposition, or even to "false bedding."

We did our best, during our study of these rocks, to apply either

* The larger felspars, which are rendered distinct by saussuritization, are occasionally partly idiomorphic and seemingly crushed out.

† I collected a specimen, in 1888, from the hornblende-schists of Sark (which are practically identical with those of the Lizard), in which the bands attain a thickness of ·5″.—T. G. B.

‡ It might be urged that this rock did not belong to the hornblendic schists as here defined. It agrees, however, macroscopically with them, and differs rather markedly from the altered gabbros of the east coast, of which, moreover, we have not seen any instances on this side of the district.

of the above explanations to them. The ordinary cases, where the rock is foliated rather than banded, and the slabby bedding, which is commonly so marked a feature as to be the first thing that attracts the eye as the mass is approached, might be accounted for, like the structures in the "newer gneiss" series of Glen Logan and its vicinity, by the effects of shearing movements during a long continued process of thrust-faulting; but, in applying this hypothesis to some of the structures which are more especially suggestive of stratification, we were always encountered by difficulties which we failed to overcome. Again and again the gliding-planes, which we had devised in order to explain the oblique disposition of the apparent *stratulæ* in the rock, were interrupted by some unbroken band which either forbade the idea of any displacement, or demanded for its manufacture a contradictory set of movements. In these cases the "fluxion hypothesis" also landed us in similar difficulties. Thus, although our reasons cannot be fully appreciated by those who have not followed our steps, we are at present unable to suggest any form of mechanical disturbance as a complete explanation of the more banded members of the Hornblendic Group, and think that for these the stratification of an ash (perhaps by the intervention of water *) is the better "working hypothesis."

Subsequently, of course, there must have been almost complete, if not quite complete, rearrangement of the constituents. The ash originally must have consisted of more or less fragmental felspar, augite, iron oxide, and possibly olivine, with bits of more or less scoriaceous tachylyte or magma-basalt. Of the latter, at any rate, every trace has disappeared, the constituents have separated as from a molten mass, and the whole is a crystalline mixture of felspar, hornblende, &c.† In this hypothesis there are also difficulties, so that, until further evidence be discovered, it must be regarded as only tentative, for we now feel convinced that some members of the group were originally dolerites, and some structures are due to fluxion. Moreover, it must not be forgotten that the basic member of the overlying Granulitic Group often differs little from the more hornblendic part of the present one. The former appears to have been raised to a high temperature after it had at least begun to consolidate. It is then probable that the underlying rock was not less affected, and important changes may thus have been brought about.

### (3) *The Micaceous Group.*

This—the talco-micaceous group of De la Beche—was retained by Prof. Bonney because of the presence of a mica-schist, and some other non-hornblendic rocks, among the green schists. The last

* Because by the action of currents the materials would be to some extent separated in accordance with their specific gravity, and their deposition at any spot would be varied by the constantly changing velocity of flow.

† See, for a suggestion of the process, M^cMahon, Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 525–531.

are, indeed, the most abundant rocks, but they differ much in appearance from the normal hornblende-schists, in the minuteness of their constituents and in the presence of a more acicular variety of that mineral *. But the advance of our knowledge during the last few years leads us to doubt the advisability of making any definite separation. Three bands of brownish mica-schist, like that at Polpeor, have been discovered by Mr. Fox (and visited under his guidance by the authors), intercalated with the normal hornblende-schist in Polledan Cove, E. of Housel Bay †; and the character of the green schists may be accounted for by subsequent pressure and shearing. The whole region has evidently been greatly modified since its constituent rocks first crystallized. The mica-schist at Polpeor is crumpled, and the green schists often exhibit structures resembling the "mylonite" of the Highland thrust-fault region; tongues of a porphyritic diabase may be seen on the shore, so crushed and sheared as to be barely separable from the green schists ‡. On Old Lizard Head §, a cleavage foliation may be seen traversing the corrugated banded greenish schist at a high angle, and the rock below is in places a breccia of a gneissoid rock and of a rather soft "green schist" in hopeless confusion, very suggestive of faulting. Polkerris Cove (S. of Porthalla), in which some serpentine and a little gabbro occur, affords evidence confirmatory of this view. On the northern side we find a flinty-looking schistose rock (very similar to one variety at Polpeor), and can identify in one place a porphyritic dyke, rather like that named above. The flinty rock is sometimes porphyritic, and may be a modified dyke, but other parts suggest affinities with the hornblende-schist, into which there is a passage on the southern side of the Cove. A specimen from the northern side, which in the field seemed more nearly related to the hornblende-schist than to the diabase, has been examined. It shows marked indications of crushing and shearing; fragmental "eyes" of rotten felspar or of hornblende (sometimes very like altered diallage) occur in a sort of mosaic of minute hornblende and felspathic grains (possibly also of quartz), with a sort of "fluxion structure." One part of the slide is coarser and still retains traces of a fragmental structure; another consists of thin bands of a mosaic, in which this or that mineral predominates. Thus the passage of the normal hornblende-schist into a rather flinty-looking schistose rock in consequence of shear seems to be demonstrated ||.

* See description of the principal varieties, Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 12.

† Described by Mr. Fox in Trans. Roy. Geol. Soc. Cornw. vol. xi. pt. v. (1891). A similar mica-schist occurs near Pistil Ogo, but here in the 'green schist.'

‡ A larger and less disturbed mass occurs a little farther east, and is described in Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 4.

§ Name on the six-inch map; called 'The Quadrant' in Prof. Bonney's paper. That name is now applied to an island below.

|| The cliffs and shore do not afford a continuous section, so that a fault may escape notice. As there is a fault at Porthalla and must be one at Porthoustock, this, the only intermediate cove, may be also determined by a fault.

We therefore think that the rocks along the coast, from the coast east of Polpeor to Old Lizard Head, owe their peculiarities mainly to subsequent mechanical disturbances, probably the result of an overthrust, so that the distinctive name had better be abandoned. The coarsely crystalline gneissoid rocks discovered by Mr. Fox in the outlying islands, and so admirably described by him and by Mr. Teall, are situated, in our opinion, below the thrust plane, so that we have here an association similar to that which occurs in some parts of the N.W. Highlands of Scotland. At Porthalla, between the great fault and the typical hornblende-schist (with serpentine), a band of mica-schist occurs associated with fissile green schist. To this mass we should apply a similar explanation, and no longer desire to separate it from the Hornblendic Group *.

## IV. Igneous Rocks newer than the Serpentine.

### (1) *The Troctolite.*

This rock was described by Prof. Bonney under the name of "the older gabbro," and its resemblance to the troctolite of Volpersdorf was pointed out. Subsequent analysis indicated that it might be thus named, though it was not so typical an example. It has also been described and figured by Mr. Teall †. Thus there is little left to be said. It has been found only at Coverack Cove, where it occurs both in irregular masses and in thin veins, with little difference in the texture of the rock, and very perfectly welded to the serpentine, which is practically unaffected by it. We cannot, however, regard the association of the two rocks as a case either of segregation or of veining strictly contemporaneous, for the serpentine occasionally has been completely brecciated. For instance, one block on the shore, which measured about $2' \times 1\frac{1}{2}'$, consisted of about equal parts of the two rocks, the serpentine being mostly in rectangular pieces, the largest about $8'' \times 5''$, the smallest about $1\frac{1}{2}'' \times \frac{3}{4}''$, the thinnest vein of the troctolite being about $\frac{1}{4}''$ thick, yet nearly as coarse as the rest.

* Prof. Bonney is now convinced that Mr. Collins was right in regarding the gneissoid band (described by him) as only a pressure-modified granite vein, but both the Authors fail to understand on what grounds Mr. Collins separates the hornblende-schists at Porthalla from those in other parts of the Lizard, and considers them to be metamorphosed Lower-Silurian rocks. He states (Quart. Journ. Geol. Soc. vol. xl. (1884) p. 466) 'that the hornblende schist of Porthalla is a very peculiar rock indeed.' We cannot understand how any one well acquainted with the hornblende-schists of the Lizard could make this statement. An exceptional specimen might be found anywhere, but speaking of the general character of the Porthalla schist, which it must be remembered cannot be separated from the mass which extends to Porthoustock Cove, we unhesitatingly affirm that we cannot detect in it any valid distinction, macroscopic or microscopic, from much of that which occurs in other parts of the Lizard peninsula.

† 'British Petrogr.' pl. viii. fig. 2.

(2) *The Gabbro.*

The principal mass of gabbro, as stated in a former paper, is rudely oval in form, the longer axis measuring full four miles, and the shorter about two. It rises in Crousa Down to a height of nearly 300 feet above the sea, by which it is washed for a considerable distance north of Coverack Cove. In the Survey map it is represented as giving place to greenstone in the little cove opposite to the dangerous skerries called the Manacles. This, however, is hardly correct, for though dykes of the latter rock become rather more frequent on this part of the coast, and perhaps ultimately occupy as much space as the gabbro itself, that rock continues to Porthoustock Cove, on the southern slopes of which it may be seen; though, as will be hereafter noticed, it does not, so far as we know, descend to the water's edge.

This mass of gabbro evidently throws off many veins on its southern flank, which cut both the troctolite and the serpentine in Coverack Cove. There is also the great dyke-like mass, nearly two miles long and about a furlong wide, according to the Survey map, which runs inland roughly in a N.W. direction from the skerries of Carrick Luz, and approaches at nearest within about a third of a mile of the former mass. On either side, in Lankidden Cove on the east and towards Compass Cove on the west, dykes are numerous, doubtless in some way connected with it. They disappear in Kennack Cove, but are found again about Enys Head, and then, after a considerable interval, at Polbarrow, becoming ultimately very numerous around Pen Voose. It is, however, only at the two first-named localities that the rock is found in masses of considerable size; generally it occurs in dykes or veins (at most only a few yards, and commonly only a few feet thick) which not seldom ramify and terminate in veins sometimes less than an inch in thickness.

The mineral composition of the rock and its changes have already received full attention; therefore it may suffice to say that in its normal condition it varies from a plagioclase-olivine-augite (or diallage) rock to a saussurite-hornblende rock, the last mineral being partly actinolite, and always one of the distinctly green varieties. It is impossible in this case to prove that olivine was an original constituent, but inasmuch as it is present in certain masses, which exhibit a transition from the normal gabbro to the ordinary saussurite-hornblende rock, there is no reason for supposing it to have been originally absent from the latter. In the great mass at Crousa Down the gabbro is often comparatively unaltered. In the dykes, including the large one at Carrick Luz, it is generally more or less altered. The olivine has usually disappeared, though occasionally its position is indicated (as is rather common at Coverack) by a blotch of hematite; the augite occurs as diallage, and every stage of the change from this mineral into hornblende can be observed. The felspar in like way passes gradually into saussurite; in most cases it appears to be less stable than the diallage, for a saussurite-diallage rock is common. The change to saussurite does not appear

to be connected with any mode of dynamo-metamorphism. It is quite true that it is very characteristic of the foliated masses, but it may also be observed, as, for instance, at Coverack, in rock of the most normal character. It is evidently due to the action of water, and might more correctly be designated meteoric metamorphism, for it evidently proceeds inwards from the exterior of the mass; probably being produced when this is at no great distance from the surface.

This gabbro occasionally is distinctly foliated or even banded, a structure which during the last few years has given rise to much discussion. Prof. Bonney, in describing it, regarded the structure as the result of crystallization under a pressure (or resistance) definite in direction. Mr. Teall ascribed it to pressure subsequent to solidification *, and compared it with the *flaser*-gabbro of the Germans, which has been similarly explained. But to this view, as pointed out by the former †, and subsequently confirmed by Gen. McMahon ‡, the absence of all signs of the effects of pressure in the associated serpentine seems a fatal objection.

One of the chief objects of our visit in 1890 was to study afresh this very remarkable structure, and the conclusion at which we arrived will be most readily indicated by giving a brief summary of our observations, though this may involve some slight repetition of statements already published.

The foliated and banded structure in the gabbro is most conspicuous in the Carrick-Luz dyke; it is also locally very well developed in the neighbouring dykes, especially on the western side, in the neighbourhood of Pen Voose and at Polbarrow. It may be observed, though it is not common, in the Crousa-Down mass, and elsewhere. Every variety may be found, from a slightly streaky or wavy foliation § to a distinct mineral banding, and not seldom the pyroxenic crystals appear as "eyes." Each of these two types is excellently figured by Mr. Teall ||, so that on the present occasion it is needless to do more than refer to his plates and to the descriptions already published. The results of our investigations may be thus summarized:—

(1) As will afterwards be more fully explained, the gabbro had assumed its foliated structure before it was cut by the later intrusives (dykes of diabase, &c.), which probably are of more than one age.

(2) Whatever be the origin of the quasi-foliated structure in the serpentine, this cannot be connected with the foliation of the gabbro. The former is most marked on the western coast and at Porthalla; but these cases cannot be cited in support of the pressure-hypothesis, because gabbro does not, so far as is known, occur in either

* Geol. Mag. (1886) p. 481.

† *Ibid.* (1886) p. 575.

‡ *Ibid.* (1887) p. 74.

§ We use this term as indicative of orientation rather than of linear aggregation of constituents, producing at most a slight and interrupted 'streakiness,' from which every stage exists to distinct bands mainly of different minerals, sometimes over a quarter of an inch thick.

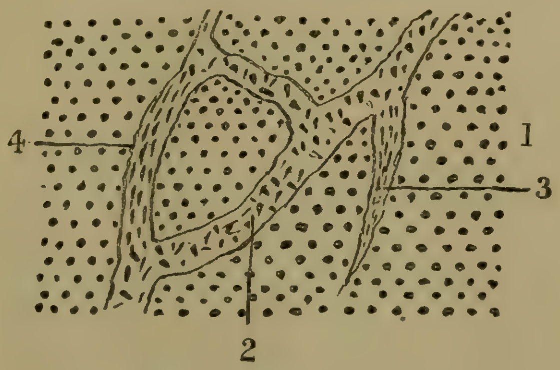
|| 'Brit. Petrogr.' pls. xxvi. and xliii.

district. The most streaky serpentine on the eastern coast, south of the Manacles, is the dark variety on either side of Caerleon Cove, but here the gabbro is not markedly foliated. The serpentine at Pen Voose, except for slight and very local crushing near faults, is perfectly normal. So it is in the neighbourhood of the great Carrick-Luz dyke, where the foliation in the gabbro is at a maximum. About Enys Head streaky serpentine and gabbro, sometimes foliated, occur together, but there does not appear to be any necessary connexion between the structures.

(3) The gabbro and serpentine are sometimes welded together, sometimes separated; the former condition is perhaps more common in Coverack Cove than elsewhere, and is more usual with the thin veins than the larger masses.

(4) The gabbro is often rather variable in texture. The great mass of Crousa Down appears to be the most uniform in this respect, and it consists of medium-sized grains, though occasionally small patches of coarser varieties occur along the coast. The Carrick-Luz mass is more coarsely crystalline. All the smaller dykes, as a rule, are coarse-grained, and even in the thinnest veins the rock generally does not become fine-grained, but maintains a medium texture. Some of the largest crystals of diallage occur in masses less than a foot thick. Even in the same mass the gabbro not seldom exhibits considerable variation in texture, the ordinary coarse kind being streaked or mottled with vaguely-defined patches of finer grain.

Fig. 4.—*Gabbro veins near a 'natural arch' on the shore, west of the Carrick-Luz mass.*




1. Serpentine.
2. Coarse gabbro.
3. Moderately foliated gabbro.
4. Very foliated gabbro.

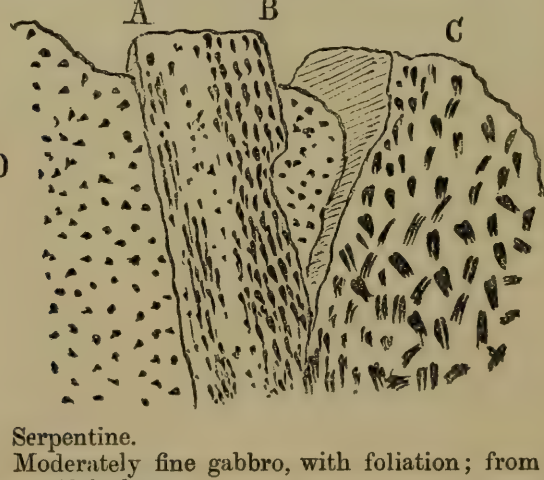
(5) The foliation sets in and disappears in a most capricious fashion. Part of a dyke, an arm of a vein, may be foliated (fig. 4), without any apparent reason or connexion with any structure in the adjacent rock (especially when this is serpentine), and the rest may be normal. The significance of the relations of the ordinary and the foliated

or banded structure, one with another and with the exterior of the mass, will best appear from a series of examples.

(*a*) In the Carrick-Luz dyke the strike of the structure appears to be fairly steady *, running rather W. of N.W., which is also the average direction of the dyke. It appears to dip at a rather high angle, 60° or more, on the northern side—that is, in the probable direction of the fissure. The mass varies somewhat in coarseness, and in the amount of foliation and of banding, the latter being more distinct on the western side, but here and there it seems inconspicuous. The felspar occasionally, the diallage frequently, are unaltered. Now serpentine yields readily to pressure. When this is moderate in amount the rock brecciates; when the pressure is more severe the fragments take a lenticular shape and become slickensided; when it is extreme, as may often be seen in the Alps, the rock assumes the appearance of a slaty schist, with corresponding changes in its microscopic structure †. Any conspicuous grains of bastite, augite, chromite, &c. are more or less crushed out. But in the Lizard serpentine these minerals, like the matrix, are in a normal condition, so that we are forced to conclude, if we adopt the pressure hypothesis, that the gabbro, one of the toughest of rocks, has been crushed into a kind of schist, while its comparatively brittle associate has undergone no structural change.

(*b*) Sometimes the foliated structure in the gabbro occurs near to and parallel with the edge of a dyke, but at others, though rarely, it is inclined at a high angle to it; it is also found in wisps or streaks in a non-foliated mass, as may be seen, for instance, at Crousa Down. The annexed diagram (fig. 5), representing part of a vein on the eastern side of Compass Cove, shows a wedge of serpentine

Fig. 5.—*Foliation of gabbro dyke east of Compass Cove.*



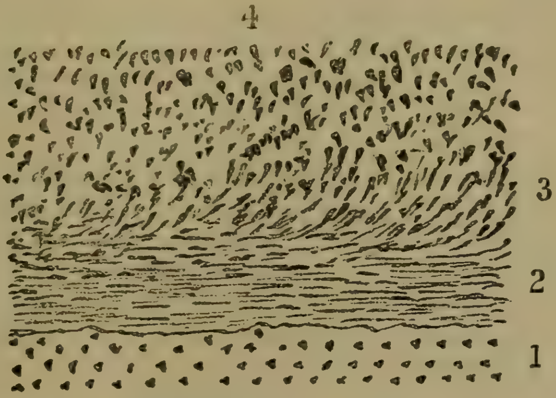

D. Serpentine.
A, B. Moderately fine gabbro, with foliation; from A to B about $4\frac{1}{2}$ inches.
C. Coarse Gabbro.

* We can answer only for the shore-section.
† Bonney, Geol. Mag. (1890) p. 533.

splitting an intrusive dyke of gabbro and enclosed in it. Of this rock the main mass is coarse, and in it foliation is either extremely indistinct or absent. In the arm we find on one side medium-grained gabbro, well foliated, passing into a compact gabbro, which is but slightly streaked with a foliated structure, as indicated. The serpentine, whether in the included block or in the main mass, shows no sign of crushing.

(*c*) Yet more significant is another mass nearer the Carrick-Luz dyke, the more important portion of which is represented in the annexed diagram (fig. 6). The face of a dyke of gabbro forms a crag about ten feet high, the lower edge resting on serpentine. Above this the mass for about two feet consists of a rather fine-grained gabbro,

Fig. 6.—*Foliation in gabbro between Compass Cove and Spernic Cove.*




1. Serpentine.
2. Foliated gabbro.
3. Partially foliated gabbro.
4. Unfoliated gabbro.

foliated or finely banded, " not unlike a piece of hornblende schist," the bands being so thin that the mass, as a whole, is rather *foliated* than *striped.* The next two feet consist of ordinary and foliated gabbro, very irregularly mixed, but the streaks, as shown in the diagram, have in places a distinct tendency to sweep round into the fine foliated mass below. Lastly comes some half-dozen feet of sporadically coarse or slightly foliated gabbro, in which occurs now and then a thin wisp-like band of the fine foliated rock, resembling that at the bottom, but not parallel with it.

Microscopic examination of these foliated gabbros has not led to any very definite results. The constituent minerals have been so much altered since the structure was produced as to obliterate any distinct indication of the agent by which it was caused. The original plagioclastic felspar has been almost wholly replaced by secondary products. Occasionally some diallage may be detected. In the *augen-flaser* gabbros the larger grains of diallage still remain comparatively unchanged, though they also often have a

border of, or are partially replaced by, secondary hornblende. Here and there, in other parts, and in the ordinary *flaser*-gabbros, some trace of the original diallage may be found amid a crowd of hornblende grains *; the former occasionally exhibit some traces of mechanical disturbance, such as a slight bending of the cleavage-planes or pinching up of an end. These indications, however, are suggestive of a strain, due to a tensile movement of the mass rather than of a crushing down of the grains. The cleavage-planes in the different grains generally, but not always, exhibit a tendency to parallelism.

The saussuritic constituent is at times fairly clear and transparent, at times brownish, varying from moderately translucent to almost opaque. The former, with crossed nicols, appears as aggregates of rather bright-coloured specks, and the original mineral seems to have occurred in rather polygonal grains, often about ·01 inch in diameter; traces of this structure also can be occasionally detected in the more opaque patches. It might be argued that this "mosaic" is a proof of crushing, but the uniform general distribution of the structure appears adverse to this idea, and it might be explained either as the result of secondary change in an original larger felspar grain †, or as an original microgranular structure ‡.

This more opaque part occurs in irregular rounded patches, in rudely rough-edged oblongs, or in streaky clots. Assuming them to represent a felspar of slightly different composition, as is rendered probable by their mode of occurrence, these patches on the whole are not at all suggestive of crushing, for though the last mode of arrangement might be so interpreted, it would be equally possible with a fluxion-structure.

(*d*) Near the Spernic Arch there are several thin veins of compact diorite intrusive in gabbro. One of these veins, about two feet thick, splits up into minor veins a few inches thick, which run with the foliation of the gabbro in a way that reminds one of the alternating white and black parallel bands of the granulitic series; but when the dioritic veins are followed up, they are seen to cut obliquely across the foliation of the gabbro at a low angle. Yet though the gabbro is *intensely* foliated, the compact trap does not give, under the microscope, any indication of crushing or any more parallelism of structure than is usually presented by the flow of

* A white or very pale augite in roundish grains is present in some examples.

† Prof. Judd on the replacement of labradorite by scapolite, Min. Mag. vol. viii. p. 186.

‡ I collected, during a visit to the "norite region," N. of St. Jerome in Canada (in 1884), a specimen of a fine-grained norite, which showed on weathered surfaces a faint structure much resembling a fluxion-structure. Microscopic examination shows that the felspar (which is well preserved) occurs chiefly in small polygonal grains (about the above-mentioned size), mixed with larger grains, often about three times the diameter, but sometimes more. The mass does not give the slightest hint of having been crushed, and we appear to have a record of crystallization *in situ*, analogous to that of a microgranite. The pyroxenic constituent, which is not abundant, is less well preserved, and irregular in outline, but appears to have formed, as best it could, *in situ*.—T. G. B.

igneous rocks. The diorite is certainly not derived, in this case, from the gabbro by shearing, and its intrusion was subsequent to the epoch when the gabbro had attained a maximum foliation.

(*e*) One more typical case may be given. On the top of the cliffs above Polbarrow there is a boss of gabbro perfectly unfoliated. A few feet below this a vein of gabbro appears in serpentine, and takes a course parallel to the top of the cliff for a few feet and then dies out. This vein is decidedly foliated, the foliation running with the direction of the vein. Down below, on the beach of Polbarrow itself, between high- and low-water marks, there is another outcrop of what appears to be a continuation of the intrusive dyke seen at the top of the cliff. A gabbro vein about a foot and a half thick runs a course nearly parallel to the beach for 31 feet, and no portion of it exhibits any trace of foliation. Here the onward passage of the gabbro appears to have been barred, and, after an ineffectual attempt to force a passage upwards, the vein turned sharply down at right angles to its former course, and finally broke into a spray of finer veins. Just at this elbow the gabbro is intensely foliated, resembling, if one may use the comparison, streaky bacon. It seems clear that pressure after consolidation can have had nothing to do with the foliation of this rock. Such pressure, had it been applied, must have affected the serpentine as well as the gabbro, but there are no signs of it. Then the pressure that converted a coarse-grained gabbro, in one portion of the vein, into an intensely foliated streaky-bacon-like mass, ought to have corrugated or streaked the other portion of the vein immediately in contact with it, but it has not done so. It ought also to have foliated the boss on the top of the cliff. It is also to be noted that the two veins which are foliated, namely the one at the top of the cliffs and the one at the bottom, run in directions at right angles to each other, the foliation in each case being parallel to the direction of the vein. These facts, which seem inexplicable on the hypothesis of crush or shearing after consolidation, seem perfectly natural on the supposition that the foliation was the result of traction or the resistance offered by the serpentine to the passage of the gabbros.

The evidence summarized above makes it impossible, in our opinion, to explain the foliation in the gabbro as a result of pressure-metamorphism subsequent to the solidification of the rock *. The structure cannot be later than this epoch, and the following hypothesis appears to comply best with all the conditions of the problem. Suppose that the mass at the time of intrusion was not at

* It must be remembered that mineral banding, which there is no reason to connect with crushing, has already been not seldom observed. It may be noted in the syenite of the Plauen'schengrund, where the usually orientated felspars occasionally form short streaky bands. It is noticed as occurring in certain granites (Hatch, 'Introduction to the Study of Petrology,' p. 83), and in the hornblende-picrite of Penarfynydd (Alfred Harker, Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 457). We have mentioned it in this paper as occurring in serpentine (*i. e.* peridotites), and have seen it in diorite and other holocrystalline rocks.

a very high temperature *, that mineral separation had already commenced, and that it consisted of crystals of felspar and pyroxene †, or—which perhaps is more probable—of completed pyroxenes and inchoate felspars, floating in a magma (having in the latter case the composition of felspar) which was already not very liquid. When the temperature was slightly lowered, as for instance near the faces of a fissure, the magma might become sufficiently viscous to exercise considerable strain upon the included crystals; they would be occasionally cracked, deformed, torn up, and aggregated in streaks; the mass also would become ill mixed; in short, it would exhibit on a large scale the phenomena of a fluxion-structure, which would be most conspicuous towards the surface, but might set in here and there in any part, or might occur like a foreign fragment owing to rupture and entanglement of portions of an outer "crust." As consolidation proceeded, the magma would sometimes continue to augment the crystals already formed, and the coarser varieties be produced; sometimes it would independently crystallize, and thus a fine-grained variety be produced or a quasi-porphyritic condition be retained ‡. In short, we offer for this rock an explanation which is in some respects similar to that which we have proposed for the banded granulites §. At any rate it is an hypothesis which meets all the conditions of the problem at present known to us, and this certainly cannot be said of the dynamo-metamorphic one.

### (3) *Varieties of Gabbro.*

As a rule, except for the above-named mineral changes, the gabbro seems fairly uniform in composition, though varying in structure and in coarseness, but a few exceptional cases have been noted. A dyke, about 2 feet thick, on Enys Head consists mainly of the saussuritic mineral; one, composed largely of rather well-preserved labradorite, occurs in Lankidden Cove ||, and another was found this year on the north side of Kennack Cove. The last does

* The coarse condition of the gabbro, even in very thin veins, might be held to indicate a very high temperature and very slow cooling, but this does not, in our opinion, accord so well with some of the other conditions.

† Doubtless with olivine and iron oxide, but we omit them as immaterial for the present purpose.

‡ Possibly also in some cases, when the gabbro may have been intruded between fault planes, a movement or movements of one or both of the walls of the fault might take place when the final stage of consolidation was setting in, and marginal shearing and foliation would be the result. Some internal shearing might also result from the same cause.

The coarseness of the rock in the thinner veins may be explained thus:—The front portion of the advancing mass would probably contain rather more crystals (as it would be rather cooler) than the rest. Thus it might for a time be arrested at the entrance of a narrow fissure, but when ruptured (owing to the pressure of the mass behind it) the fissure would be filled by a squirt of the more liquid magma, which would sweep along with it the minerals in the more crystallized portion.

§ The occurrence of an analogous structure in granite was described, and a similar explanation was suggested, by Gen. M^cMahon, Geol. Mag. (1887) p. 76.

|| Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 905.

not exceed 1 foot in thickness, and is bordered apparently by rotten serpentine; but within a few inches on the south side is a thin mottled band, which may be a rotten gabbro. The rock externally is generally light-coloured, but within is seen to consist of a smoke-grey coloured felspar, with slightly oily lustre, probably labradorite, in fairly large crystals, and of a few conspicuous flakes of a dark mica. Its microscopic structure is difficult to describe. There are some flakes of mica—one or two being biotite, the rest a white mica, with inclusions of iron oxide between the cleavage-planes, and so probably a "bleached" biotite; one or two tufts of a nearly colourless mineral in more or less acicular fibres, most likely actinolite; a grain resembling a serpentinized olivine (it is not quite normal in character), the rest being a closely connected group of minerals, felspars or their alteration-products. This consists partly of fair-sized grains of a felspar which, in general appearance and extinction, corresponds with labradorite, but does not exhibit the usual oscillatory twinning: partly of a mosaic of crystals and crystalline grains, which in places assume the "saussurite" condition already described. The mode of occurrence and association of these with the larger crystals does not suggest that the latter have been broken up by mechanical pressure; rather that parts of them have undergone a molecular re-arrangement. They project irregularly, sometimes with rectilinear outlines, into the larger grains, and sometimes a single grain or group of grains, with either form of outline, appears insulated in the felspar, like an island near a coast-line. One is reminded of the formation of scapolite from labradorite described by Prof. Judd, though these grains are not the former mineral, but seemingly are also felspar. Cleavage-planes can be seen, and the line of extinction makes with them angles varying up to at least 30°.

## V. Manacle Point and Porthoustock Cove.

Prof. Bonney was unable, when working for his former paper, to make more than a hasty traverse of the rocks of Manacle Point, so we examined the coast-sections from a cove on the south to Porthoustock Cove *. Over the greater part a gabbro dominates, generally about as coarse as the normal rock of Crousa Down, though occasionally a very coarse variety is found. Sometimes also it becomes rather fine-grained, the change from one to the other being often fairly rapid. A foliated structure occurs, though but rarely. As at Pen Voose, the gabbro is broken into by a granular rock, sometimes porphyritic, sometimes green-spotted, sometimes dull greyish and speckled. Both these are cut by a rather compact greenstone, which is occasionally slightly porphyritic; of this not much is seen on the south side of the Point, the quantity seeming to increase as we go northwards †.

The south side of the actual cove at Porthoustock is very puzzling, and in places the crags could only be examined from a boat in very

* That is, the whole area coloured as 'greenstone' in the Survey map.

† We reserve the details of these rocks for the next section.

calm weather. We had to restrict ourselves to what could be seen by working along their face; so we cannot attempt more than to give a general sketch. Gabbro of the ordinary type can be traced at intervals on the slope above the cliffs, certainly to within a furlong, and probably to within a hundred yards of the water's edge.

These cliffs, as far as we could get at low water, were found to consist of a greenstone (epidiorite)*. This is cut by veins of a felspathic rock, which must be classed with the actinolitic gabbros, since it consists mainly of moderately coarse plagioclastic felspar and small patches of an actinolitic mineral, probably replacing augite. Sometimes the veins are very thin and might be infiltrations. One or two indeed appeared to contain quartz, and if so the rock might almost be called a felspathic pegmatite. This rock and the greenstone are closely welded; the former differing markedly from the normal gabbro, which, as mentioned above, occurs on the hillside at a short distance. Both are traversed by dykes of compact greenstone, macroscopically indistinguishable from that which cuts the ordinary gabbro about Manacle Point, but in one of them a porphyritic structure occurs. This variety, under the microscope, is found to be a compact epidiorite, containing large crystals of plagioclase felspar. There can be little doubt that the matrix was formerly a minutely crystalline, or possibly even a vitreous, basalt.

The relations of the first and second rock much resemble those of the Granulitic Group, but in the present state of our knowledge it would be rash to do more than note the resemblance; certainly, as the gabbro-like rock proves to be so different from the ordinary gabbro of the district, we are not justified in regarding them, without further proof, as of the same age. One difficulty in the identification of the first two rocks with the Granulitic Group is that they are little, if at all, foliated, while the crags facing them across the narrow cove are "slabby," and sometimes well-banded, hornblende-schist. Much minute study and repeated visits will be necessary in order to clear up the difficulties of this section of the coast.

## VI. Other Intrusive Rocks.

As has been often remarked, the schists, the serpentine, and the gabbro are alike cut by intrusive dykes. These are more numerous along the east coast than on the west, being especially common between Caerleon Cove and Porthoustock. To classify and describe them fully would require a separate memoir. On the west coast the serpentine is not seldom cut, as described in Prof. Bonney's paper, by dykes and small masses of a reddish, rather fine-grained granite, which generally is distinguishable, macroscopically and microscopically, from the granitic rock of the Granulitic Group, which,

* It consists chiefly of plagioclase felspar in good condition (probably labradorite) and a fibrous hornblendic mineral, clearly of secondary origin. Probably the original was a rather fine-grained dolerite with a structure inclining to ophitic. Larger idiomorphic crystals of rotten felspar occur rather sparsely.

as already stated, also occurs on that coast. One or two intrusions of the same rock are found on the east coast. For instance, there is a well-marked vein in a cove north of Pen Voose *, and another (badly exposed and so not quite certain) south of the same, at the farther end of the beach. Dykes of a porphyritic diabase are occasionally found cutting the Hornblendic Group, as, for example, near Polpeor (where it has been already described), on Carnbarrow, near Ogo-dour Cove, and at the headland to the south, where there are two dykes, one fine-grained, the other (and later) porphyritic with a compact base. This very interesting section has been described by Mr. Fox, with notes by Mr. Teall †. The granite veins which we have noticed above in the Hornblendic Group are more probably approximately synchronous with those in the Granulitic Group, and so are anterior to the date of the serpentine. The last rock and the gabbro are repeatedly cut by basic dykes, many of which have been noticed by previous writers. Of these there are numerous varieties; most of them are now hornblendic rocks, but it is probable that many, if not all, were originally augitic. In a few cases, as once or twice in Kennack Cove, they are practically indistinguishable from the dioritic members of the Granulitic Group, and we have to rely upon field evidence, but in many no such difficulty exists. Occasionally they exhibit an approach to foliation, as in the well-known dyke on the south side of Caerleon Cove, the exterior of which exhibits a slightly foliated structure; this we now consider, after careful re-examination, to be due to differential movements during solidification, not to subsequent pressure, for the mode in which the structure occurs agrees better with the former hypothesis, and there is nothing to support the latter. The dykes in the serpentine at Coverack, and in the Crousa-Down gabbro, have already received some notice, but one or two additional details concerning the latter may be worth adding. As already stated, it is frequently traversed by dykes of a basic rock, which varies from compact to granular, and is sometimes slightly porphyritic. Of these dykes, however, we have not thought it necessary to examine more than about a dozen specimens in all, four or five of which are from the gabbro. The former have been magma-basalts, and sometimes at the edges almost tachylytes. They are more or less altered, but numerous lath-like crystallites, with occasional small scattered crystals, of plagioclase can still be recognized, and small oval or oblong greenish patches, occupied by an aggregate of flakes giving bright colours with the crossed nicols, probably indicative of the former presence of larger grains of an augitic mineral. Others, fine-grained but holocrystalline, may be classed as epidiorites; one at least is still an ophitic dolerite.

But the gabbro is also cut by another rock, which, though similar,

* This was discovered by Messrs. Fox and Teall; we have not seen it, for the rock-face is only visible from the sea, but they secured photographs which we have examined. This is an interesting case, because the granite cuts the gabbro, as it was said to do by De la Beche, a fact of which Prof. Bonney did not succeed in finding a proof (Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 915).

† Trans. Roy. Geol. Soc. Cornwall, vol. xi. pt. iv. (1890) p. 213.

appears separable from the above-named groups of dykes. It seems often to break up the gabbro, and then to cement the fragments, so that the two form one mass, while the above-mentioned cut clean, as dykes, through both, being sometimes welded, sometimes separable. It is slightly speckled, somewhat dark on freshly fractured surfaces, weathering a rather warm grey, sometimes porphyritic (felspar), sometimes green-spotted. A specimen from near Manacle Point consists of plagioclase, augite, partly altered into a brown hornblende, altered olivine, and granular magnetite; it is therefore a fine-grained gabbro. The boundaries of the grains are very irregular, and the augite not seldom includes either lobes or grains of the felspar *. The normal gabbro presents a similar structure, but has less magnetite, and the pyroxenic constituent is either diallage or is altered to a fibrous actinolite, with a little of the brown hornblende; the felspar also is more decomposed. The boundary between the two is not very sharply defined under the microscope. Macroscopically the dark rock at Pen Voose, which is similarly associated with the gabbro, much resembles the above, but in the three specimens examined hornblende (green) alone is present; magnetite is scarce in this rock. This also has a granular structure, but the individual grains are smaller and rather more regular in shape, so it differs more conspicuously from the adjacent gabbro (in which also the augitic constituent is replaced by hornblende). This rock was probably an early intruder; nevertheless, at that time the gabbro was not only crystalline but foliated, as can be seen on careful scrutiny in one or two instances at Pen Voose, for the subangular fragments of foliated gabbro are scattered in the dark matrix as if they were bits of a schist †.

Lastly, there are two dykes which differ in some respects from all those already mentioned. The others have a distinctly rhyolitic aspect. One occurs on the road leading from Landewednack to the back, or sea-face, of the serpentine quarry between Church Cove and Pen Voose, forming a vein a few inches thick in serpentine. As it weathers to a similar colour, the outcrop is easily overlooked ‡.

* Compare plate iv. figs. 2, 3, illustrating Prof. Judd's paper on 'Tertiary Gabbros,' &c. in Scotland and Ireland in Quart. Journ. Geol. Soc. vol. xlii. (1886).

† I made a mistake in regard to the relations of these two rocks at the time of my earlier visits, which affects a few lines in my first paper, viz. those on p. 894:—'The gabbro and hornblende-schist are here mixed up ............... intrusive.' The close resemblance, macroscopic and microscopic, of the rock described above to some of the less foliated and unbanded varieties of the hornblende-schist (or the darker part of the Granulitic Group) led me to suppose that the gabbro was the intruder, and had acquired its foliation from pressure in cooling; but, on re-examination, I find that there are difficulties which did not then occur to me (for parts of the supposed hornblende-schist closely resemble an unmodified igneous rock), and that the foliation in the gabbro cannot be thus explained. The evidence, even at Pen Voose, now appears to me more favourable to my present view; and that which we obtained in the neighbourhood of Manacle Point, where there are similar appearances in a less altered rock, seems convincing. This, however, does not affect the general argument of that part of the paper.—T. G. B.

‡ It has been examined by Gen. McMahon.

The rock has a specific gravity of 2·59. The microscope proves it to be composed of two imperfectly-mixed glassy magmas, exhibiting very typically the fluxion-structure of a rhyolite. In transmitted light one of these magmas is quite colourless, the other has a buff-coloured porcellanous appearance. Under crossed nicols the slice breaks up into a cryptocrystalline matrix, showing minute irregular-shaped flecks of doubly-refracting matter. Here and there, more particularly in the colourless portions of the magma, the matrix becomes microcrystalline, showing very minute doubly-refracting dots, presumably quartz, on a dark ground. The slice is dappled with chlorite and contains some magnetite, ferrite, a misshapen porphyritic felspar, and polysynthetic granules of quartz.

The second dyke is at Housel Cove. This, in petrological character, is closely related to the last one; it cuts right across the bedding of the hornblende-schists, and is in contact with these schists along its western margin. On its eastern side it is separated from the schists by a few feet of breccia, made up of fragments of the felsite and doubtless of "mechanical" origin, for it is parted from the solid rock by a fault, the walls of which are clearly indicated by well-marked slickensides. On the western margin of the dyke the hornblende-schists are somewhat crushed and rotten, and have acquired by weathering a superficial resemblance to the felsite breccia.

Examined under the microscope, this rock has quite the aspect of a rhyolite, and its structure so closely resembles the rock above described that the details would be a mere repetition of those already given. Granules of quartz and felspar may be made out in the base here and there, but they rarely present anything like crystallographic outlines. The slices are sprinkled with leucoxene and they are full of dots and strings of magnetite partially converted into ferric oxide. Fluxion-structure is pronounced. In some cases the dots of iron have been removed by aqueous agencies, giving the slice a pseudo-vesicular character. The Housel-Cove rock contains more iron than the Landewednack specimen, and so has a slightly higher specific gravity, viz. 2·62.

## VII. Some Fragmentary Inclusions.

(1) Fragment (about 3″ in diameter) included in dioritic rock (Granulitic Group), Kennack Cove. The rock resembles a hornblendic gabbro. It is very slightly streaky in structure. Under the microscope it is found to consist of plagioclase felspar almost replaced by the usual filmy decomposition-products, of aggregated green hornblende, usually in rather small, rudely shaped prisms, some grains of brownish iron oxide, and a fair amount of sphene and apatite. The gabbro-like rock on the south side of Porthoustock Cove, it may be noted, also contains these two minerals, which, so far as we have seen, are rare in, if not absent from, the ordinary gabbro (that intrusive in the serpentine).

(2) From a slab-like fragment, a few yards long and less than

a foot thick, included in the great mass of gabbro near Carrick Luz. This was shown to one of us in 1886 by Mr. Teall. The rock is of a pale pinkish red colour and looks like a felstone or microgranulite, being much more fine-grained than either the granitic rock of the granulite, or the granite which is intrusive elsewhere in the serpentine. Under the microscope it exhibits a microcrystalline structure, the quartz and felspar (rather decomposed) forming a mosaic of rather polygonal grains; but there are one or two larger grains of felspar with an irregular outline indicative of a porphyritic structure, and in one or two instances the grains of this mineral are arranged in short "streaks." There is some little iron oxide, a flake or two of colourless mica, and a grain or two of (?) zircon. The evidence as to the relation of this rock to the gabbro is not decisive, but appearances, macroscopic and microscopic, favour the idea of its being an included fragment.

(3) A fragment of slaty rock of a pale greenish grey colour, somewhat splintery in shape, in the same mass of gabbro on the west side of the headland. The line of demarcation between it and the gabbro is sharp, and it is obviously not a concretionary patch. The slaty fragment is perfectly compact *. It has a sp. gr. of 2·90, a hardness of 5 to 5·5, and it fuses very readily with intumescence to a dark brown coloured glass which is not magnetic. It is partially soluble in hot hydrochloric acid, and still more so in hot sulphuric acid, the solutions yielding lime, magnesia, alumina, and a little iron. The residue was readily soluble in hot hydrofluoric acid.

A thin slice of the slaty inclusion examined under the microscope is seen to consist of a colourless hornblende, profusely dotted over with granules of sphene. The hornblende, being without colour, does not exhibit any pleochroism. The refraction-index is normal, judged by the relief and the well-marked character of the outlines; but the double refraction, indicated by the colours in polarized light, is unusually weak. The mineral is closely packed together in small lath-shaped, irregular club-shaped, and in idiomorphic prisms; here and there it is somewhat platy, or even leafy, in form. A cleavage, running with the length of the prism, is often well developed; but occasionally the prism is divided by a single transverse cleavage. One well-developed idiomorphic prism gives the typical prismatic cleavages intersecting each other at angles varying from 123° to 125°. Extinction, measured from a single cleavage, ranges from 13° to 19°, and averages 16°. Cross-sections exhibit an optic axis in polarized light inclined to the plane of the section, and prisms and sections showing a single cleavage have the major axis of elasticity at an angle of about 74° to the plane of cleavage on the side of the prism. The whole of the groundmass appears to be composed of this lime-magnesia-alumina hornblende, very poor in iron.

Hornblende, as is well known, when melted under the conditions which obtain in a laboratory, consolidates in the form of augite—never as hornblende; and the existence of augite crystals surrounded

* Examined by Gen. M Mahon.

by secondary hornblende in igneous rocks would seem to indicate that, in *some cases* at all events, partial refusion near the earth's surface may account for the formation of such an amphibolite. Hence one observer * has remarked:—"Where the composition of both minerals [viz. augite and hornblende] is identical, temperature alone is sufficient to determine which crystalline form is assumed." Without wishing to dogmatize on a matter regarding which our information is at present imperfect, the authors think that the slaty inclusion affords good *primâ facie* evidence that the gabbro, after it caught up the fragment of slate, was never in a highly heated condition.

## VIII. Summary of Results.

The chief results of the investigations described in this paper may be briefly summed up under the following heads:—

(1) That the Hornblendic and Granulitic Groups, whatever their genesis may have been, were substantially in their present condition at the time when the rock, which is now a serpentine, was intruded.

(2) That this rock was formerly some variety of peridotite—dunite, saxonite, lherzolite, &c., occasionally a picrite †; that the foliated or banded structure, which is perceptible in it in certain districts, does not result from pressure posterior to solidification of the rock-mass, but from movements in it while it was still in a molten or partially molten condition.

(3) That the foliated or banded structure sometimes present in the gabbro does not result from pressure subsequent to the solidification of the rock, but it also is a kind of fluxional structure, due probably to movements when the rock was in a condition of rather imperfect fluidity, and consisted of a mixture of crystals and of a magma more or less viscid.

(4) That the Granulitic Group consists of at least two distinct rocks, one acid, the other basic, of which the former was intrusive in the latter, but that, either in consequence of this or from some other cause, the temperature of the whole mass became sufficiently elevated in certain localities to allow of movements as in the last-mentioned cases, which have produced the remarkably uniform and stratified aspect of the two varieties; this movement being followed by crystallization, or completion of crystallization, in the constituents.

(5) That the Hornblendic Group consists in part of igneous rocks; that it may be indebted for its structure partly to movements anterior to consolidation, partly to pressures of later date, but that it is difficult to explain all the phenomena either by the one or the other cause, so that at present the possibility of some portions having resulted from the alteration of a stratified basic ash must not be left out of sight.

* G. H. Williams on Baltimore Gabbros and Diorites, Bull. U.S. Geol. Surv. vol. iv. (1886) p. 46.

† Viz. an augite-olivine or hornblende-olivine rock, in which a small and rather variable proportion of felspar or an aluminous silicate is present.

(6) That earth-movements have produced marked effects only at the extreme north and the extreme south of the district; these, in the former, modify the rocks for a very limited distance from the boundary faults. In the latter the results appear to be on a somewhat greater scale. To this cause we attribute the "slatiness" characteristic of the so-called Micaceous Group. Probably the latter rocks are separated from the coarse gneisses of the outlying islands on the south coast by a fault of low hade towards the north, which emerges near the base of the present cliffs.

## EXPLANATION OF PLATE XVI.

Fragment of banded serpentine (natural size) picked up at foot of cliffs, Porthalla (p. 474). C is a joint-face, from which cracks, now closed by light-coloured steatite, run for some little distance into the mass. Below AB is a similar structure which, together with the change in the character of the serpentine, suggests the possibility of one variety being intrusive into the other. It may, however, only be another old joint-plane now closed. This structure is described in Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 22.

## Discussion.

Mr. Teall said that he had no general theory as to the relations of the Lizard rocks. The views of the Authors as to the origin of the Granulitic Group were not opposed to those which he had expressed. They went farther than he had done, and maintained that the deformation was connected with the intrusion of the granite. There was a difference between him and the Authors as to the origin of the foliation in the gabbro; but, as he had no new facts to offer, he did not wish to reiterate or to retract his opinions on this subject.

The Rev. Edwin Hill had accompanied the Authors with preconceived opinions that the Granulitic Group had something sedimentary in it, and that the gabbro-banding had something to do with cooling at the surfaces of the intrusive masses. But he had been constrained to admit that the granulitic banding was due to injection by one rock into another. This other possibly had a pre-existing structure sufficient to determine the lines of injection; but it was not necessary to assume such. So with the banded gabbro, the evidence for the Authors' conclusions seemed complete. Though "convinced against his will," he did not remain "of the same opinion still."

Prof. Hull wished to call attention to the remarkable resemblance between some of the geological phenomena described so lucidly by the Authors of the paper and those of some parts of Ireland, particularly in the Connemara and Donegal highlands. This resemblance might be recognized in the cases of inosculation of granitoid with hornblendic masses, and the presence of serpentine breaking through in dyke-like manner the older rocks. In Connemara there were two varieties of serpentine: first, the dense, heavy, dark green variety, which was, in all probability, a transformed augitic or


BANDED SERPENTINE FROM PORTHALLA.

olivine rock, of igneous origin; and, secondly, the ophicalcite, consisting of calcite and serpentine intermixed and generally banded. He was glad that the Authors maintained the original igneous origin of the Cornish serpentine, which most resembled the former variety in the West of Ireland. With regard to the banding of the dykes of gabbro where they were in contact with the walls, he observed that this was a structure not uncommon amongst dykes of igneous rock, and he believed it to have originated during the cooling process. These bands were, in fact, planes of cooling, and the structure of the rock along the walls of the dyke contrasted with the central portions, where the cooling process was slower, and allowed the formation of a more crystalline rock in which these planes were absent.

The President remarked that the questions discussed in the paper had far more than a mere local interest. In particular, the problem of the banded structures among crystalline schists touched some of the profoundest difficulties of the theory of metamorphism. There was ground, he thought, for believing that mechanical deformation had been rather too freely appealed to as an explanation of the general banded and schistose structures of the older rocks. This cause had unquestionably been largely instrumental in the production of such structures; but, as he had stated in his Anniversary Address, there were features of the more ancient gneisses which it was hard to imagine could be due to anything else than some original variations in the arrangement of the materials of the rock before solidification. He had been much struck with the extraordinary way in which some of the Tertiary gabbros of Skye simulate the rudely-parallel wavy lenticular banding of different materials in many gneisses; and he thought it was rather among such examples of flow-structure in eruptive rocks that the analogies of some of the structures of the gneisses were to be sought. The Authors had, therefore, in his opinion, done a service in recalling the attention of geologists to this view of the subject.

General McMahon said that, as those who had taken part in the debate appeared to agree generally with the conclusions arrived at by the Authors, he would confine himself to calling special attention to one of the specimens exhibited, and to a brief description of a section which he thought had an important bearing on the subject under discussion.

Prof. Bonney stated that the theory suggested by Prof. Hull had been, in substance, formerly held by himself, but that he had found cases for which it did not suffice. The case quoted by the President was of great interest, and he might add that since the paper was written he (the speaker) had seen others. He could not sit down without testifying to the value of Mr. Teall's work at the Lizard, and begged the Society to remember that General McMahon was the originator of the right idea (as the speaker believed it to be) as to the foliation of the gabbro.

27. *The* Cross Fell Inlier. By Prof. H. A. Nicholson, M.D., D.Sc., F.G.S., and J. E. Marr, Esq., M.A., Sec. G.S. (Read April 8, 1891.)

[Plate XVII.]

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## § I. Introductory.

Since the "Description of an Insulated Group of Rocks of Slate and Greenstone in Cumberland and Westmoreland, on the East side of Appleby," given by Dr. Buckland in the Transactions of the Geological Society (ser. 1, vol. iv. (1817) p. 105), a considerable number of papers have been devoted to the Lower Palæozoic rocks of that region, but as references to these are given in Mr. Whitaker's list of papers bearing upon the geology of the Lake District, published in the late Mr. Clifton Ward's memoir on "The Geology of the Northern Part of the English Lake District," it is needless to insert here an account of the bibliography of the area. An excellent summary of the work which has been achieved is given by Mr. J. G. Goodchild in a paper published in the Proceedings of the Geologists' Association for 1889*. In this paper also considerable additions are made to our knowledge of the rocks of the Inlier, and to these we shall have occasion to refer.

In the present paper, we have attempted to fix the ages of the various formations of Lower Palæozoic rocks in the Cross Fell district, to determine their organic contents, and to compare them with the corresponding rocks of other areas, rather than to give a detailed description of the general structure of the region. This latter will no doubt be done by the officers of the Geological Survey who have been engaged in mapping the district, with far fuller evidence than is at the disposal of those who have not examined the region in an exhaustive manner. Nevertheless, as a general knowledge of the structure of the region is necessary to understand the details which follow, we have drawn up a rough map which will serve as a guide until such time as the official Survey map is published, and we append a description which may serve to render the principal features intelligible.

* Proc. Geol. Assoc. vol. xi. p. 258.

## § II. General Description of the Inlier.

The Cross Fell Inlier of Lower Palæozoic rocks is marked by the occurrence of a group of pyramidal hills, stretching in a band from half a mile to a mile in width, for a distance of about 16 miles in a general N.W. to S.E. direction on the west side of the Pennine escarpment, from a little north of the village of Melmerby on the north to the south-west flanks of Roman Fell on the south. It is bounded by two great faults, which enclose it as an elongated spindle-shaped mass. The eastern fracture, which may be termed the Escarpment Fault, brings the Lower Carboniferous rocks against those of Lower Palæozoic age, whilst the western one, the Pennine Fault of the older writers, and which Mr. Goodchild terms "the Outer Pennine Fault," places the Lower Palæozoic rocks in juxtaposition with the New Red Sandstone for many miles. The lenticular inlier between these faults is furthermore broken by another great N.W. and S.E. fault, bringing Lower Ordovician rocks on the east side against the Higher Ordovician and Silurian strata of the west. This is "the Middle Pennine Fault" of Mr. Goodchild; but as a great part of the displacement here was produced at a much earlier date than that due to the other two faults, we consider it better to speak of it as the Knock Pike-Flagdaw Fault, as it is well seen between the two hills bearing those names. It is true that subsequent movement has occurred on this line along part of the course of the fault, so that at the north end of the Inlier the Lower Carboniferous rocks are included between the Ordovician and New Red Sandstone deposits, but to the south the fault is seen to pass under the Carboniferous conglomerates of Roman Fell with little or no disturbance of those rocks, and emerges again on the south-west side of the hill where the Lower Palæozoic rocks are developed.

By means of the Knock Pike-Flagdaw Fault the lenticular inlier is divided into an older eastern and a newer western portion, and it will be convenient to describe these separately, commencing with the older rocks which lie to the east of the Knock Pike-Flagdaw Fault. Unfortunately none of the rocks which occur on that side of the fault are seen to the west of it, and consequently a considerable gap occurs in the succession here, though how great it is hard to say.

## § III. Detailed Description of the Strata.

a. *The Eastern Portion of the Inlier.*—Most of the sedimentary rocks on the eastern side of the Knock Pike-Flagdaw Fault have been referred to the Skiddaw Slates, but as only few fossiliferous localities have been detected in this area, the correlation has been made to a large extent from similarity of lithological character. As the evidence furnished by these rocks is at present insufficient to establish a detailed sequence, we shall content ourselves with a very brief notice of the deposits, for it will be necessary to devote

considerable attention to the Skiddaw Slates of the more central portion of the Lake District before their minute subdivisions can be satisfactorily determined.

We believe that the oldest rocks of the Cross Fell Inlier occur in the extreme north-eastern portion of the inlier in the neighbourhood of Cuns Fell, where they are probably separated by yet another N.W. to S.E. fault from the newer rocks to the west. Here, in the course of Dry Sike and Hungrigg Sike, a series of greenish shales are seen dipping in a general south-westerly direction at a high angle. These shales furnished the obscure fossil described by one of us in the Geol. Mag. for 1869 (pl. xviii. D) as possibly of vegetable origin; but this affords no clue as to the precise age of the series. They are succeeded to the south by blacker shales and grits which bear considerable resemblance to the older Skiddaw Slates of the Lake District, and they are probably contemporaneous with these, though no fossils are recorded from them in this area, and we have found none. Similar beds are again seen farther south at Brownber, and in the streams adjoining it, and they continue over a considerable part of the ground east of the Knock Pike-Flagdaw Fault, as far south as Roman Fell. At Brownber (and in a few other places such as Murton Pike and the neighbourhood of Keisley) they have undergone great disturbance, and are penetrated by numerous quartz-veins, which are folded with the strata, causing considerable changes in the rocks, as notified by one of us at the Newcastle meeting of the British Association in 1889. Mr. Alfred Harker has kindly examined sections of these rocks for us, and has furnished us with an appendix to our paper, giving descriptions of these and other rocks of this area.

Next in order of age we would place the black shales, which occur repeated thrice, firstly in Ashlock Sike and the neighbouring tracts east of Ousby, next in Ellergill and the adjoining ground under Cross Fell, and lastly in the course of Knock Ore Gill. These strata—which we term the "Ellergill beds"—have yielded an abundant harvest of fossils, of which a list is given in Prof. Lapworth's paper on "the Geological Distribution of the Rhabdophora"*, most of them being well-known Upper Arenig forms.

At the summit of the beds referred to the Skiddaw Slates, Mr. J G. Goodchild locates his "Milburn Group," consisting, as he has pointed out, of a series of slates alternating with submarine tuffs. These are excellently displayed in Wythwaite Hole, and in the streams to the south of it, where they are also intercalated with lavas. Few fossils have yet been discovered in them, but Mr. Goodchild records *Didymograptus Murchisoni*, Bœck, and we have found *Diplograptus dentatus*, Brongn., so that the beds are probably closely related to the Ellergill Group, from which they differ in the occurrence of the volcanic material. Mr. Goodchild rightly insists upon the importance of his discovery as throwing light upon the vexed question of the relationship of the Skiddaw Slates to the volcanic

* Ann. & Mag. Nat. Hist. ser. 5, vol. iii. p. 23, sep. cop.

rocks of the Borrowdale Series, but into this question we cannot enter here. Mr. Harker has examined slides of rocks from the Milburn Group of Wythwaite and the neighbourhood, and his description will be found in Appendix I. to this paper.

Though all the bedded rocks on the eastern side of the main inlier are either shales or lavas and ashes interstratified with shales, we do get another group of volcanic rocks on the east side of the Knock Pike-Flagdaw Fault in a subsidiary inlier which lies east of the village of Melmerby, and which is separated from the main inlier by a band of Carboniferous conglomerate, a few score yards in width, abutting against the New Red Sandstone. At the south end of this small inlier a group of basic rocks, consisting of ashes and porphyritic and vesicular lavas, is separated from a group of rhyolitic rocks by the above-mentioned fault. Unfortunately, owing to the intervention of the Carboniferous beds, which are here faulted down, the relationship of the basic lavas and ashes to the shales farther south is not seen. That these basic volcanic rocks are the equivalents of the Eycott lavas was recognized by Mr. Goodchild *, and a porphyritic rock, of which a beautiful specimen from Rake Brow is preserved in the Museum of Practical Geology (London), is quite similar to one of the well-known porphyritic Eycott lavas †. Unfortunately this group of rocks is flanked by Carboniferous rocks or by faults on all sides, so that its true relationship to the other rocks of the district is not shown.

The rocks of the eastern half of the inlier are also marked by the intrusion of a considerable quantity of igneous matter, and as an examination of the intruded rocks is of importance as throwing light upon the general sequence of events in the district, we may give a brief account of their development.

The principal masses occupy the prominent ridge of Cuns Fell, and the slopes of Thack Moor. Cuns Fell is formed mainly of diabase running in a general north-east to south-westerly direction, and sending off a considerable tongue to the south. On the east side of the hill, in Ousby Dale, much felsitic rock is associated with the diabase, under such conditions that it is difficult to make out the relations of the two rocks, though on the summit of the hill a felsitic dyke is undoubtedly intrusive in the diabase. Whether or no the felsitic rocks are the newer, they probably belong to the same general period. That they were intruded before the end of Silurian times is rendered probable by the absence of cleavage in the highly baked shales below the mass, and by the existence of a schistose structure in the diabase, seen at the spring in Ousby Dale. This appears to indicate that they were intruded previously to the exertion of the pressure which has folded and cleaved the rocks, and we are inclined to believe that the masses are of the same general age as the volcanic material which forms the Borrowdale series, and are related to the volcanic outpourings of that group.

* Trans. Cumb. and Westm. Assoc. vol. ix. (1884) p. 183.
† For notes on these rocks see Appendix I.

It is noticeable in this connexion that we get several complexes of acid and basic intrusive rock in the North of England, such as might well supply material for the formation of the Ordovician lavas. The rock of Thack Moor is chiefly felsitic, and though it covers a considerable amount of ground, it is usually much decomposed at the surface. Two other felsitic masses occur to the south of this, one parallel with the Maiden Way and the other beneath Cocklock Scar.

The only other intrusive rock to which we would call special attention is a broad mica-trap dyke seen in Dry Sike, east of Melmerby, and which is of interest from the greater metamorphism produced along its margin than is usual with this class of rock in the North of England.

b. *The Western Portion of the Inlier.*—The rocks on the western side of the Knock Pike-Flagdaw Fault consist exclusively of the upper portion of the Ordovician and the lower part of the Silurian rocks, so that along the line of the above-mentioned fault the greater part of the Borrowdale series of rocks appears to have been cut out. The general strike of the rocks is N.W. and S.E., showing a marked divergence from that which characterizes the beds of the more central portions of the Lake District.

One of the principal features of this half of the Inlier is the existence of a set of N.E. to S.W. faults, which causes frequent repetition of the Upper Ordovician and Lower Silurian rocks. By these faults the west side of the Inlier is divided into a series of rectangular or triangular blocks, with a similar succession in each, and it will save space if we describe in some detail the block which exhibits the most complete section, and afterwards note similarities and discrepancies.

The rhyolitic pyramidal hill known as Dufton Pike is separated from the similar hill of Knock Pike to the north by one of the above-mentioned transverse faults, which may be spoken of as the Cosca Fault. To the N.E. of this fault, the stream called Swindale Beck runs along the south-east flank of Knock Pike to the village of Knock, and in it the following section is displayed (Pl. XVII.).

The line of the Knock Pike-Flagdaw Fault is here marked by an intrusive mass of mica-trap noticed in Appendix I. The shales on the east side of the fault, the dyke itself, and the rhyolite are all exposed in a small quarry by the side of the moorland road, N.W. of the beck. Below this a capital exposure of the rhyolite (2) which forms Knock Pike is seen in the course of the stream. It is succeeded by thin layers of rather fine, apparently unfossiliferous ashes, which seemingly pass up into the remarkable beds numbered 3 in the section. These consist of calcareous shales, with nodular masses of limestone, crowded with fossils, some of the calcareous bands being exclusively composed of the valves of *Beyrichia*. One bed of the series has been spoken of by Professors Harkness and Nicholson * as the "*Discina-corona* bed," and we propose to name

* Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 463.

the series the "*Corona* Series." The fossils contained in the series are of great interest, and altogether different from those embedded in the overlying strata. We append a list of those which have been found in the stratum in this stream:—

*Beyrichia Wilckensiana*, Jones.
*Primitia semicircularis*, Jones and Holl.
*Lingula tenuigranulata*, M'Coy.
*Strophomena grandis*, Sow.

The series (4) consists mainly of black and blue shales, often calcareous, interstratified with bands of calcareous rock which have undergone considerable disturbance. These are the well-known Dufton Shales. Their fauna is quite similar to that of the main division of the Coniston Limestone of the Lake District, so that whether we suppose that this is a more specially shaly base of the Coniston Limestone series, or an argillaceous representative of the whole of that series, we are fully persuaded that these Dufton Shales are of the age of the Coniston Limestone, and not an underlying deposit as has been previously asserted. We have found in the Dufton Shales of this stream the undermentioned fossils:—

*Dicellograptus complanatus*, Lapw. (?).
*Diplograptus socialis*, Lapw. (?).
*Calymene senaria*, Conr.
*Cybele verrucosa*, Dalm.
*Illænus Bowmanni*, Salt.
*Phacops Brongniartii*, Portl.
*Remopleurides Colbii*, Portl.

At the point where a tributary stream (Rundale Beck) enters Swindale from the east, the Dufton Shales are succeeded by a very calcareous deposit, numbered 5 in the section. This consists of thick beds of whitish limestone with peculiar ashy-looking green shales. Though this deposit at first sight bears far stronger resemblance to the ordinary Coniston Limestone than do the Dufton Shales, an examination of the fossils indicates clearly that it is not Coniston Limestone, but is the equivalent of a thin band at the base of the Ashgill Shales in the Lake District, which one of us has previously referred to (Quart. Journ. Geol. Soc. vol. xli. (1885) p. 487) as the "*Staurocephalus* zone." We may speak of this limestone as the "*Staurocephalus* Limestone"; in Swindale it has yielded the following fossils, which are mostly found in the interstratified calcareous green shales:—

*Echinosphærites arachnoideus*, Forbes.
*Turrilepas.*
*Acidaspis.*
*Illænus Bowmanni*, Salt.
*Lichas laciniatus*, Wahl.
*Phacops Jukesii*, Salt.
*Phillipsinella parabola*, Barr. (?).
*Staurocephalus globiceps*, Portl.

*Trinucleus seticornis*, His.
*Orthoceras* sp.

No. 6 of the section consists of blue shales with *Strophomena siluriana*, Dav., and the undermentioned fossils, all found in the corresponding Ashgill shales of the Lake District:—

*Phacops mucronatus*, Brongn. (?).
*Orthis biforata*, Schloth.
—— *elegantula*, Dalm.
—— *protensa*, Sow.
*Orthisina* sp.
*Strophomena siluriana*, Dav.

Above the Ashgill Shales, a strike-fault cuts out the Skelgill beds in the main stream, but they are found in the tributary stream, Rundale Beck. These and the deposit No. 7 of our section (the Browgill series) have been previously noticed in our paper "On the Stockdale Shales," and we have nothing to add to the description given therein. The Browgill beds pass up as usual into the blue flags with *Monograptus vomerinus* (No. 8), which appertain to the Lower Coniston (Brathay) Flags, and which represent the Wenlock Shales of other areas. These, as shown in the map and section, abut against the New Red Sandstone (No. 9) which is thrown against them by the Pennine Fault just east of the village of Knock.

In continuing our description of the rocks it will be convenient to consider the blocks into which the west side of the Inlier is divided by the cross-faults. The block to the south of the one last described is about two miles long, and is bounded on the south by the Harthwaite Fault. It is occupied by a greatly disturbed syncline having the rhyolites of Dufton Pike to the north-east, and those of Wharleycroft with a thin band of andesite (the latter probably the oldest rock seen in the western half of the Inlier) to the south-west. Between these the moory country is mainly occupied by the Dufton Shales, well exposed in Hurning Lane, Pusgill, Dufton Town Sike, Billy's Beck, and Harthwaite Beck. That they are much disturbed is shown, not only by the great crumpling which they have undergone as seen in actual section, but by the occurrence of lenticular outliers of higher strata on the S.W. slope of Dufton Pike, at Pusgill House, and near the head of Billy's Beck, and of an inlier of lower deposits in Harthwaite Beck, against the Harthwaite Fault.

The principal point to be noticed concerning the rocks of this block is the very fossiliferous character of the "*Corona*-beds" of Pusgill, of the Dufton Shales of Pusgill, Dufton Town Sike, and Billy's Beck, and of the *Staurocephalus* Limestone near the head of the latter, containing, amongst other fossils, *Staurocephalus globiceps*, Portl., and a new species of *Skenidium*.

South of the Harthwaite Fault is a triangular block apparently extending to Murton, though no exposure has been seen by us in

its southern portion. In this block comes the Keisley Limestone, to the consideration of which we must devote a few words. It is well known that the mass of limestone at Keisley, which has been frequently described, is a white or pink crystalline rock, often crowded with fossils. It occupies the southern part of Keisley Bank, and appears to be of considerable thickness, having a general southerly dip at high angles. That it is faulted against the rhyolitic series of Keisley Bank, Harthwaite, and Gregory is evident, for it rests on an ash at the east end of the block, whilst to the west it reposes on the rhyolite which forms the summit of Keisley Bank and widens out westward. This fault is also apparently one of low hade. The limestone itself shows signs of much disturbance: it contains twisted wisps of shale in places, and the occurrence of beds containing numerous *Illæni* with their convex surfaces uniformly pointed downwards indicates inversion. A list of the fossils has been previously published, but as additional forms have been found and corrections must be made in this list, we here append a fresh one:—

*Halysites* sp.
*Lindstrœmia* sp.
*Primitia Maccoyii*, Jones.
*Ampyx tumidus*, Forbes.
*Cheirurus bimucronatus*, Murch.
—— *cancrurus*, Salt.
—— *clavifrons*, Dalm. (?).
*Cyphaspis* (?) cf. *triradiatus*, Törnq.
*Cyphoniscus socialis*, Salt.
*Cytheropsis phaseolus*, His.
*Homalonotus punctillosus*, Törnq.
*Illænus Bowmanni*, Salt.
—— cf. *conifrons*, Billings.
—— sp.
*Lichas laciniatus*, Wahl.
—— *laxatus*, M'Coy.
*Remopleurides*, cf. *longicostatus*, Portl.
*Sphærexochus calvus*, M'Coy.
*Atrypa expansa*, Lindstr. (?).
*Orthis Actoniæ*, Sow.
—— *porcata*, Sow.
—— *testudinaria*, Dalm.
—— *vespertilio*, Sow.
*Strophomena corrugatella*, Dav.
—— *deltoidea*, Conrad.
—— *expansa*, Sow.
—— *rhomboidalis*, Wilckens.
*Loxonema obscura*, Portl.
*Orthoceras* *, cf. *elongatocinctum*, Portl.

* For notes on this and other Cephalopods, see Appendix II. kindly supplied to us by A. H. Foord, Esq., F.G.S.

It has been generally recognized that this list indicates the Coniston-Limestone age of the deposit. Nevertheless, unequivocal Dufton Shales are found only one-third of a mile away in a stream between Keisley and Wharleycroft, and probably approach close to the limestone.

We believe that the Keisley Limestone may have been thrust in a north-easterly direction for some distance, and that the limestone bands have been thickened by folding during this process, whilst the shales have been to a large extent squeezed out. On the other hand, the Dufton Shales have probably had their argillaceous members largely repeated, and the limestones pulled out into lenticular masses. This seems to us the mode of explaining the great difference in the lithological characters of two deposits occurring close together and containing fossils of the same age, which accords best with the observed facts, though before finally accepting it we would advocate a closer study of similar lenticular masses of limestone which occur elsewhere, and, so far as we are aware, always in disturbed districts.

Another block occurs to the south of the one just described, and is terminated by a fault on the S.W. flank of Roman Fell, east of the farmhouse of Fell Dikes. It is also about two miles long, and is remarkable chiefly on account of the interesting development of the "*Corona*-beds" shown on the western slopes of Roman Fell, which have been noticed by Mr. Goodchild *, who rightly records the existence of Lower Bala fossils in that locality. These "*Corona*-beds" are situated above the rhyolite of the flanks of Roman Fell, and doubtless pass under the Dufton Shales of the Hilton Beck Smelt Mill. Three principal subdivisions are noticeable in Lycum Sike and the streams to the south. Resting on the rhyolite are pink ashes with *Orthis testudinaria*, Dalm., in abundance. Above these are pink shales with fine examples of *Trematis corona*, Salt., and *Lingula tenuigranulata*, M'Coy, whilst the highest beds seen, which abut against the Pennine Fault, are very calcareous ashy beds crowded with gasteropods and lamellibranchs, and containing occasional specimens of the two above-mentioned horny brachiopods.

The pink staining noticeable in these rocks is no doubt due to percolation from the overlying conglomerates.

One more block is found south of this: a cross-fault once more brings up a mass of rhyolite, which runs southward for one third of a mile, when it is cut off at Howgill Fold by the great fault which brings down the Carboniferous conglomerates as vertical beds converted into quartzite (see Appendix I.).

This block is chiefly noticeable on account of the re-appearance of the Knock Pike-Flagdaw Fault from under the conglomerate, so that a small triangular patch of leaden-grey shales appertaining to the rocks of the eastern side of the Inlier is seen on the hillside north of Howgill Fold.

The last block to be noticed occurs in the extreme north of the

* Proc. Geol. Assoc. vol. xi. (1890) pp. xcv & 263.

district, forming a great part of the subsidiary inlier which has been already noticed as furnishing representatives of the Eycott volcanic rocks. These basic rocks are faulted against the rhyolitic lavas and ashes of Shield Green, east of Melmerby. Above the highest lava is an ash apparently unfossiliferous, and the possible equivalents of the "*Corona*-beds" succeed it in the form of green ashy fossiliferous shales, which are exposed on a fell-road leading out of the Alston Moor road. These however, may belong to a somewhat lower horizon. They contain the following fossils:—

*Prasopora Grayæ*, Nich. & Eth. Jun.
*Amphion pauper*, Salt. (?).
*Cyphaspis megalops*, M'Coy (?).
*Trinucleus Goldfussi*, Barr. (?).
*Orthis testudinaria*, Dalm.

Above these calcareous ashes are greatly-disturbed calcareous ashy shales, which belong either to the "*Corona*-beds" or to the base of the Dufton Shales. They are seen on the high road, and have yielded:—

*Prasopora Grayæ*, Nich. & Eth. Jun.
*Callopora pillula*, Nich. & Eth. Jun.
*Diplograptus* sp.
*Agnostus* sp.
*Trinucleus seticornis*, His. (?).
*Lingula tenuigranulata*, M'Coy.
*Orthis elegantula*, var. (?), Dalm.
—— *plicata*, Sow.
*Triplesia* (?) *spiriferoides*.
*Strophomena rhomboidalis*, Wilckens.

Above and beyond these are representatives of the Stockdale Shales.

One more subsidiary inlier north of this shows the highest Lower Palæozoic beds seen in this district. These are the Coniston Grits which are seen dipping in a southerly direction in Limekiln Beck. A specimen of these grits has been long exhibited in the Museum of Practical Geology, and the deposit has been recognized by the officers of the Geological Survey as belonging to the Coniston Grit Series.

## § IV. Ages of the different Members of the Coniston Limestone Series.

We have already compared the earlier and later accumulations of the Cross Fell area with their equivalents in the main part of the English Lake District, and we need only add a few words concerning the rocks which lie between the rhyolites and the Stockdale Shales, for these are more fully developed here than in other parts of the North of England.

(a) Corona *Series.*—The principal variations in the lithological characters of this group were described when discussing the succession in Swindale Beck and on Roman Fell. They appear to consist essentially of calcareous ashes, with their limestones, the ashy matter becoming more abundant and coarser as we go southwards; though if the beds on the Fell Road at Melmerby actually belong to this division, this statement must be modified, for they also contain much ashy matter. It is, however, possible that they are on a somewhat lower horizon than the *Corona*-beds proper, as has been already suggested. They somewhat closely resemble the Balclatchie beds of the Girvan district, but a much larger collection of fossils than that which we have acquired must be made before a definite opinion as to their age can be offered.

We have already mentioned the fossils found in the *Corona*-beds at Swindale Beck, where the fossils are not very numerous. In other localities the yield has been far more abundant, and we append a list of the forms we have obtained from these beds:—

| | |
|---|---|
| *Monotrypa* sp. | Pusgill. |
| *Conchicolites gregarius*, Nich. | Pusgill; Roman Fell. |
| *Ateleocystites* sp. | Roman Fell. |
| *Beyrichia Wilckensiana*, Jones. | Pusgill; Roman Fell. |
| *Primitia semicircularis*, Jones & Holl. | Pusgill. |
| *Homalonotus rudis*, Salt. (?). | Roman Fell. |
| *Lingula tenuigranulata*, M'Coy. | Pusgill; Roman Fell. |
| *Orthis testudinaria*, Dalm. | Roman Fell. |
| *Trematis corona*, Salt. | Pusgill; Harthwaite Beck; Roman Fell. |
| *Ambonychia gryphus*, Portl. | Pusgill; Roman Fell. |
| *Bellerophon acutus*, Sow. (?). | Roman Fell. |
| —— *bilobatus*, Sow. | Pusgill; Roman Fell. |
| *Actinoceras Pusgillensis*, n. sp. | Pusgill. |
| *Cyrtoceras* (?). | Roman Fell. |

The gasteropods and lamellibranchs which occur so abundantly on Roman Fell, and less numerously at Pusgill, would require the attention of a specialist for their satisfactory determination. The genera *Ctenodonta* and *Pleurotomaria* appear to be represented by several species.

These *Corona*-beds seem to be older than anything which has been referred to the Coniston Limestone Series in the main Lake District. Their fauna is a very marked one, and is entirely different from that of the ordinary Coniston Limestone; and we are not aware of any similar fauna having been recorded in the British area, though it is probable that when the fossils of the Ardwell Group of the Girvan district are described they will be found to present considerable affinities to the forms which we have found in Westmorland.

Abroad, we have two calcareous deposits whose faunas are closely related to that of our *Corona*-beds, viz.: the *Beyrichia*-limestone of

Scandinavia, and the Trenton Limestone of North America. As the overlying *Trinucleus*-shales of the former region, and the Utica Slates and Hudson-River beds of the latter, can be closely paralleled with the succeeding Dufton Shales of the Cross Fell district, it seems highly probable that the *Corona*-beds may be on about the same horizon as the *Beyrichia*-limestone and the Trenton Limestone. When the beds of Wales and the Welsh border-land have been worked out in greater detail, we may expect to find a similar fauna recorded from beds situated between the Llandeilo and Bala Limestones.

(b) *Dufton Shales.*—We have already given a list of fossils from these beds as developed in Swindale. The annexed list shows those which we have obtained from other localities:—

| | |
|---|---|
| *Diplograptus truncatus*, Lapw. | Hurning Lane. |
| *Acidaspis*, n. sp. | Pusgill. |
| *Ampyx tetragonus*, Ang. | Pusgill; Billy's Beck. |
| *Calymene senaria*, Conrad. | Pusgill; Hurning Lane; Dufton Town Sike. |
| *Cybele Loveni*, Linnrs. | Dufton Town Sike. |
| —— *verrucosa*, Dalm. | Pusgill; Dufton Town Sike. |
| *Homalonotus bisulcatus*, Salt. | Pusgill. |
| *Lichas laxatus*, M'Coy. | Pusgill. |
| *Trinucleus concentricus*, Eaton. | Pusgill. |
| —— *seticornis*, His. | Pusgill; Hurning Lane. |
| *Youngia trispinosa*, Nich. & Eth. | Pusgill; Hurning Lane. |
| *Leptæna sericea*, Dalm. | Pusgill; Hurning Lane. |
| —— *transversalis*, Wahl. | Hilton Beck. |
| *Lingula ovata*, M'Coy. | Hilton Beck. |
| *Orthis biforata*, Schloth. | Dufton Town Sike. |
| —— *testudinaria*, Dalm. | Pusgill; Harthwaite Beck. |
| —— *vespertilio*, Sow. | Dufton Town Sike. |
| *Strophomena expansa*, Sow. | Harthwaite Beck. |

Most of these fossils are common in the Coniston Limestone, the Bala Limestone, and the *Trinucleus*-shales of Sweden, and there is no doubt that the Dufton Shales, if not actual representatives of the Coniston Limestone, are far more closely allied to it than to the underlying "*Corona*-beds" with which they have hitherto been associated.

(c) *Keisley Limestone.*—As to the general age of this there is no doubt. The group of fossils is essentially that of the Coniston Limestone. At the same time, the occurrence of some forms which have not been found nearer than the Chair of Kildare may indicate that we have here a fossil zone which is not represented by fossiliferous beds in the central part of the Lake District.

(d) Staurocephalus-*Limestone*, and (e) *Ashgill Shales.*—As these beds are quite similar to the corresponding strata of the Lake District, it is unnecessary to say anything further about them.

## § V. Conclusion.

Although the rocks of this district are so greatly disturbed, an examination of the richly fossiliferous deposits indicates beyond doubt, in most cases, the original order of succession of the strata. We find that, though in general the deposits are similar to those of the adjoining Lake District, there are important variations in detail, especially with regard to the Coniston Limestone group, and we feel convinced that a study of this Cross Fell area is absolutely necessary to the right understanding of the sequence of events which marks the history of the Lower Palæozoic rocks of the North of England.

## EXPLANATION OF PLATE XVII.

Fig. 1. Map of the Cross Fell Inlier on the scale of one inch to a mile.
Fig. 2. A portion of the same on the scale of two inches to a mile.
Fig. 3. Section in Swindale Beck on the scale of six inches to a mile.

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## APPENDIX I.—Petrological Notes on Rocks *from the* Cross Fell Inlier. By Alfred Harker, Esq., M.A., F.G.S., Fellow of St. John's College, Cambridge.

### 1. Skiddaw Slates.

It will not be practicable here to deal with more than the leading rock-types of a rather complex area. Further, as my own acquaintance with the district is slight, and most of the specimens studied were collected by Prof. Nicholson and Mr. Marr, these notes will not aim at being more than merely descriptive, and must be regarded as only supplementary to the field-work embodied in the foregoing paper.

The general character of the Skiddaw Slates is known from the descriptions of numerous writers on the Lake District. In particular, the occurrence in the group of subsidiary volcanic rocks has been indicated on the Geological Survey maps and in Mr. Clifton Ward's Memoir. It will be sufficient here to notice certain modifications of the slate-rocks due to metamorphic agencies, and to describe two or three examples from the volcanic portions of the group.

The evidences of dynamo-metamorphism in the Skiddaw Slates of Brownber, &c., have already been pointed out by Mr. Marr. Judging from his specimens, the rocks thus modified still part along the surfaces of original deposition, as marked out by alternations of purely argillaceous and more gritty bands; but on the wavy

divisional surfaces thus obtained are seen minute wrinkles having the same direction as the broader undulations, while a cross-section shows that these small folds have for the most part passed into little parallel faults making a high angle with the bent surfaces of lamination. In a thin section [913]* the gradual passage of the minute folds into reversed faults is beautifully exhibited, and many more are brought to light than can be detected in a hand-specimen. There are sometimes as many as two or three hundred in an inch, or even more. All the appearances recall the micro-structure of the "gnarled" beds near Amlwch, &c., in Anglesey †. In the specimens from Brownber the wrinkled lamination-surfaces present a dark and glossy aspect, which the microscope shows to be due to the development of a chloritic or micaceous mineral in the rock.

The chief secondary product is a flaky mineral showing the strong cleavage of the micas, chlorites, &c., and giving sensibly straight extinction. The flakes vary from pale greenish-yellow to colourless, the absorption being stronger for vibrations parallel to the cleavage-traces than for those perpendicular. The least axis of the ellipsoid of optic elasticity is at right angles to the cleavage. The birefringence, roughly estimated by comparison of the polarization-tints with those of quartz, is usually about 0·012, but sometimes as much as 0·014. These figures correspond in the table of Lévy and Lacroix to clintonite and delessite respectively. Further, there are in places small colourless flakes giving much higher double refraction and agreeing in character with muscovite. It is evident that, besides the dominant chloritic mineral, a micaceous one is also present, and the appearances suggest that the latter represents a further stage of metamorphism than the former. The brilliantly polarizing mica appears only on planes of actual discontinuous movement in the slate or in little isolated flakes in the gritty bands, and these are evidently the places where the mechanical stresses developed would reach a maximum. It appears that the discontinuous movement in the mass of the rock has been effected after the production of the chloritic mineral which almost completely pseudomorphs the original argillaceous material, and the flakes, except where they have been dragged along in the slipping, lie obliquely to the little faults.

The gritty bands in the rock sometimes retain their clastic appearance, but in some cases their appearance suggests recrystallization *in situ*. The constituents are quartz and felspar, among which occur sparsely flakes of the chloritic mineral and the colourless mica. The quartz often shows something of the "undulose" or "spectral" polarization indicative of a condition of strain. The felspar is frequently twinned, and seems to embrace both orthoclase and an acid plagioclase. The perfectly pellucid character of the little crystal-grains and, in some places, the fashion in which they

* The numbers in square brackets refer to the microscopic rock-sections in the collections of the Woodwardian Museum, Cambridge.

† See Rep. Brit. Assoc. for 1885, pp. 839, 840.

fit into one another can scarcely be explained except on the supposition that they have been recrystallized under the influence of mechanically produced stress.

These metamorphosed slates of Brownber contain pseudomorphs of limonite, about a tenth of an inch in diameter, evidently replacing cubes of pyrites. The pyrites has been formed *in situ*, for occasional grains of quartz, &c. are enclosed. Moreover, its decomposition has been subsequent to the crushing of the rock, for the cubes are not sensibly distorted. Indeed, the movement of the rock about the pyrites-crystals has been such as to leave vacant spaces, afterwards filled by secondary quartz. This quartz has a rather fibrous structure, and is arranged at right angles to the faces of the pyrites cubes. It is found only on those parts of the cubes where the pressure would be relieved by the flowing movement of the rock-mass, and the phenomena are precisely similar to those which I have elsewhere described as common in pyritous slates *.

As to modifications produced by thermal agency, a few words will suffice. The Skiddaw Slates show some degree of metamorphism near their contact with the Cuns Fell diabase. A slice in Prof. Nicholson's collection is a well-laminated rock, in which numerous minute grains of clastic quartz are mingled with the argillaceous material. It is marked throughout with irregularly ovoid spots, one-fiftieth to one-hundredth of an inch in diameter. Along certain bands these spots are merely clear patches due to the dusty (carbonaceous ?) matter having been expelled, to collect just beyond the margin. In other bands the clear spots thus left behave optically in a different way from the surrounding ground, being mostly dark between crossed nicols. The quartz-sand occurs indifferently inside and outside the spots, and the grains have lost nothing of their sharpness of outline.

Near the large lamprophyre dyke in Dry Sike, again, the Skiddaw Slates appear highly metamorphosed, being converted into a very compact black rock with a certain degree of lustre and a conchoidal fracture, like some varieties of *hornfels*. A slice of this rock, which is rather a microscopic grit than a true slate, shows as the chief metamorphic product a rather obscure chloritic mineral. The numerous minute quartz-grains retain their angular outline [912].

Among the lavas occurring in the Skiddaw Slate group, an interesting rock was collected by Mr. Marr in the stream north-west of Master Sike [920]. It is an andesite consisting essentially of an isotropic base crowded with very minute felspar-microliths. These only occasionally show any parallel arrangement, although a streaky fluxion-structure is seen in the mass as a whole. There are a few small porphyritic felspars with good outlines. No augite is recognizable, though its former presence is probably indicated by the pale delessite-like substance filling some small ovoid vesicles in the rock. The interesting point is a vesicle about a twelfth of an inch in length, with a complex structure recalling in some respects

* Geol. Mag. (1889) pp. 396, 397.

that of the *lithophysæ* in some acid lavas. There are, however, novel peculiarities. The cavity has been at one time lined with a thin coating of a pale-green chloritoid mineral, which for brevity may be called delessite. It has a fibrous structure, with partial fan-like grouping, roughly perpendicular to the surface on which it was deposited. From this surface it has for the most part broken away, so as to divide the cavity by partition-walls, not however continuous. A second coating of the same material has also to some extent become detached, and with it portions of the andesitic matrix itself. Subsequently crowds of minute but perfectly-formed felspar prisms have been formed, clustering especially, with a tendency to perpendicular growth, on the detached fragments of andesite where these were not protected by a coating of delessite. Finally, all the remaining space has been occupied by clear crystalline quartz. The little felspar-crystals are clear, and invariably have twin-lamellation. The birefringence is very near that of quartz, and sections nearly perpendicular to the twin-plane give extinction-angles up to about 18°. These characters do not distinguish between albite and andesine. The curious feature is the clear evidence that the felspar-crystals were formed within the vesicle subsequently to the deposition of the usual coating of green decomposition-product.

A few days after the preceding paragraph was written, Mr. W. Maynard Hutchings informed me of his independent discovery of felspar within the vesicles of some Lake District rocks, and the specimen which he kindly lent me showed relations in some respects analogous to those briefly described above. The subject is one which will no doubt repay further investigation, and we may expect that Mr. Hutchings's work will throw light on this curious mode of occurrence of felspar.

The rock exposed in Wythwaite Hole seems to be a contemporaneous lava of more crystalline type (dolerite), but is too deeply altered for minute study. Besides evident spherical vesicles, there are seen under the microscope little irregular spaces occupied by quartz-mosaic, but the manner in which the lath-shaped felspars project into these renders it doubtful whether the spaces were originally vacant [1321].

A very singular rock occurs on Wythwaite Top. To the eye, it appears a coarse ash or fine breccia. Besides minute glistening felspar-crystals in the general mass, there are little fragments which themselves enclose felspars. In a slice [1322] the fragmental character is scarcely apparent. Idiomorphic felspars are scattered through the rock, showing twin-striation of the ordinary kind, occasionally crossed by pericline-lamellæ. Rarely there is a grain of quartz of clastic appearance, or a green pseudomorph which seems to come from a rhombic pyroxene. The general ground of the rock appears in ordinary light partly turbid, partly clear, the two occurring in intermingled irregular patches. The turbid portion presents a finely "felsitic" appearance, but the clear ground consists almost entirely of a mass of perfectly pellucid small crystals

and grains of felspar. Most of these have twin-lamellation and often an imperfect prismatic shape, so far as their crowded occurrence permits. Others are only once twinned, and some shapeless simple grains, with a tendency to occur interstitially, are perhaps quartz. The structure of these patches and the limpid nature of the felspars are characteristic of metamorphic rocks, and point unmistakably to recrystallization of the rock *in situ.* Any doubt is removed by an examination of the porphyritically disposed felspars already noticed. These are frequently bent and broken, and there seems to be some secondary twin-lamellation induced by stress. The most striking feature, however, is the replacement of the original turbid crystals by new felspar-substance exactly similar to the little striated felspars in the general ground of the rock. Some of the original crystals do not show this alteration; others are partially changed; and others, again, are totally converted into clear crystalline aggregates, preserving only the outline of the crystal from which they have been formed. The newly-formed triclinic felspars, cut perpendicular to the twin-plane, give a maximum extinction-angle of about 18°. This agrees with albite, though a certain variety of andesine would give the same value. A curious point about the dynamo-metamorphism is the seemingly capricious manner in which it has affected the mass of the rock.

As an example of the ordinary fine ashes of the Skiddaw Slate group, a rock from Burney was sliced [921]. It shows plenty of felspar-crystals, or more frequently broken portions of crystals, some showing twin-lamellation, others not. The general mass of the rock has probably been a felspathic dust, but now contains a quantity of quartz and calcite, besides pyrites and yellow opaque spots of ferruginous matter. Of these the quartz seems to be the latest-formed, occurring in little continuous patches of ragged outline and enclosing other decomposition-products. Little, if any, of this mineral is in original grains, and there is no indication of detrital material mingled with the volcanic.

The grits in this group of rocks are derived from the disintegration of igneous rocks of more than one kind. A specimen from the north side of Mudgill Sike [964] was found to consist essentially of grains of quartz, unrolled crystals of plagioclase, and rather rounded fragments of a microlithic andesite. A few rolled granules of decomposing augite occur, and a fragment of quartz-porphyry showing a microgranitic groundmass and a portion of a porphyritic quartz. The quartz-grains, which are the most abundant constituent, are mostly subangular to rounded, but some of the smaller ones are quite angular. They are for the most part clear, though some contain rows of fluid-pores. The felspars are sometimes penetrated by apatite needles, and resemble those which occur porphyritically in many andesites. In sections perpendicular to the albite twin-plane the extinction-angles range up to 13° or 14°. The rock contains a little calcite, partly in pseudomorphs after felspar. Other authigenetic constituents are pyrites and a little quartz, the latter sometimes forming narrow veinlets.

## 2. Basic Lavas of Melmerby.

The porphyritic lava of Melmerby presents in hand-specimens a striking appearance. Glassy-looking felspars, up to half an inch in length, showing to the eye both Carlsbad and albite twinning, are embedded in a dark compact ground. One is strongly reminded of the well-known porphyritic lavas of Eycott Hill, and closer examination leaves no doubt as to the identity of the rocks from the two localities. The type is a rather unusual one, the composition being decidedly more basic than that of normal andesites, while on the other hand olivine is wanting, being in a sense represented by a rhombic pyroxene with abundance of free iron-ore. Perhaps the best name would be hypersthene-basalt.

In specimens from Eycott, Mr. J. Hughes * found the silica-percentages 53·30, 52·60, and 51·10; Mr. T. Cooksey † found 53·40 and 52·73. The Melmerby rock is so similar that an analysis is scarcely necessary. A determination of its specific gravity gave 2·753, the figure for the Eycott rock being 2·754 (Cooksey, *loc. cit.*).

The porphyritic felspars are often grouped in such a fashion as to interfere with one another's growth, while always presenting crystal-faces to the surrounding matrix. They are on the border-land between labradorite and bytownite, being apparently a little more basic than the type hafnefjordite, $Ab_1An_3$. In sections perpendicular to the lamellæ of albite-twinning the extinction-angles range up to 37°, reckoned from the twin-line. This is for the greater part of the crystal: the border gives a rather lower angle. As regards habit, extinction-angles, zonary structure, inclusions, &c., Mr. Teall's ‡ accurate description of the Eycott felspars may stand equally well for these.

The chief feature of the groundmass is the plentiful occurrence of a rhombic pyroxene, almost often to the exclusion of augite. This is also the case in the Eycott rock, as was first pointed out by Prof. Bonney (*loc. cit.*). The mineral is, however, invariably replaced by bright-green fibrous bastite. The strong colour and pleochroism of this substance, with the occurrence in it of abundant secondary iron-ore, point to a ferriferous variety of pyroxene, hypersthene rather than enstatite. The groundmass of the rock contains plenty of magnetite. In tolerably fresh specimens [1250, 1251] this shows the outlines of octahedral crystals, and is clearly original; but in more weathered examples the whole mass of the rock is rendered almost opaque by the separation of secondary magnetite with other decomposition-products. The felspars of the groundmass are probably not very dissimilar in nature to the larger felspars; they occur in small slender prisms, but always show albite-lamellation, and do not sink to mere microliths. There appears to have been some augite, in small granules now represented by calcite and a pale almost isotropic material; and there

* J. Clifton Ward, Monthly Microscop. Journ. (1877) vol. xvii. p. 246.

† T. G. Bonney, Geol. Mag. (1885) p. 80.

‡ 'Brit. Petrogr.' (1888) pp. 225–227.

must have been a considerable amount of unindividualized base. The general characters of the groundmass bring the rock nearer to the normal basalts than to the andesites.

### 3. Rhyolitic Rocks.

The normal rhyolitic rocks do not differ in any marked way from those underlying and intercalated in the Coniston Limestone of the Lake District. Both lavas and ashes are found. The lavas are not conspicuously porphyritic, though little felspars are often scattered through the rock: these, as usual, are plagioclase. The rocks show a generally compact appearance, light grey or cream-coloured when not stained by iron oxide. The groundmass has probably been to a great extent glassy, when the rocks were fresh, but this has not always been the case. A rock from the beck north of Keisley, for instance, has a microlithic character.

The specimen just mentioned [919] shows a kind of flow-brecciation, which I believe is not an uncommon feature. Very similar appearances are seen in some of the Caernarvonshire rhyolites. In the Keisley rock the fragments of the original lava, probably the broken-up crust of a *coulée*, are divided by a matrix, or system of irregular branching veins, which makes up quite half of the whole mass. This matrix seems at first sight to consist of rather finely crystalline quartz; but closer scrutiny serves to detect in some of the clear grains the rectangular outline and the twinning of felspar. This matrix, therefore, must be regarded not as an infilling of vein-quartz entirely subsequent to the formation of the rock, but rather as an inflowing of the highly acid mother-liquor from which the earlier portion of the rock was formed, and so as representing only the latest phase in the consolidation of the lava. In one place the matrix contains an amygdaloidal cavity, some twentieth of an inch in length, on the border of which crystallization is rather better developed, and the felspar-twinning of some of the crystal-grains is well seen. The slide shows some genuine vein-quartz which occupies little cracks traversing the microlithic fragments and their matrix alike, and the contrast of these with the latter can be easily observed.

Other rocks in the neighbourhood of Keisley are ashes, and one from Harthwaite Beck is a vesicular andesite with finely microlithic ground [1283]. It is noteworthy that here, as elsewhere among our Ordovician lavas, a vesicular structure is much rarer in the rhyolites than in the andesites.

A well-marked type of acid lava is exemplified by a specimen from Gregory Hill near Dufton, "the second rhyolite below the Keisley Limestone." A slide of this rock in Prof. Nicholson's collection [L. D. 28] shows a groundmass enclosing a few scattered felspars, which, when not too much decomposed, give faint indications of twin-striation. The ground has in natural light a mottled appearance owing to numerous clear spots, with a tendency to rounded outline, from which some dusty material seems to have

been eliminated. These spots consist of crowds of exceedingly fine microliths, doubtless of felspar, embedded in quartz, which in each spot behaves as a single crystal. The darker portion of the ground has similar microliths, but in a matrix which remains dark between crossed nicols. The spots, about one-hundredth of an inch in diameter, make up most of the rock, which has a superficial resemblance to certain "spotted slates." In describing a somewhat similar structure in the rhyolites of Penmaenbach *, I was inclined to regard the crystallization of the quartz in the spots as an original character, but the point is not quite clear.

The rhyolitic rocks exposed in Swindale Beck show some remarkable features. The dominant type, as seen in the field and in hand-specimens, is a compact pale-salmon or cream-coloured rock, in which darker grey patches, with sharply defined outlines, indicate included fragments. Under the microscope [822] the greater part of the groundmass is obscure, owing to secondary quartz. There is a well-marked, rather wavy parallel structure which might be the lamination of a fine ash, though it is more like the flow-structure of a lava; and the scattered felspar-crystals, rarely broken, lie with their long axes in the same direction. There are numerous little included fragments of a microlithic andesite, and these would naturally cause the rock to be regarded as an ash, were it not for a special structure well shown in the slide. This is the occurrence of discontinuous bands or narrow streaks, following the flow-lines in the rock, in which a thoroughly crystalline texture is developed. These crystalline streaks consist of clear felspar, often in lath-shaped crystals showing twin-striation, some quartz, and, between the felspars, little areas of pale decomposition-products, such as usually indicate vanished augite. This Swindale Beck rock is, therefore, a "eutaxitic" lava, which has caught up fragments of the rocks, andesitic and others, through which it has broken out. A eutaxitic structure, though of rather different type, has been noticed in certain Caernarvonshire rhyolites (*op. cit.* pp. 21, 22).

### 4. Acid Intrusive Rocks and Transitional Types.

The acid intrusive rocks of the district are quartz-porphyries, which do not call for much remark. The best known is the so-called "Dufton granite," which forms a small boss to the west of Dufton Pike. It is a rock of red colour, resembling some of the "granite-porphyries" in general appearance. Besides abundant red felspars, it shows quartz-grains about a quarter of an inch long, and small flakes of black mica. Scattered through the rock are hexagonal plates of white mica, up to an inch in diameter; while occasionally is seen a colourless felspar-crystal, perhaps an inch and a half long, with the markedly tabular habit, the glassy lustre, and the longitudinal fissures (following an orthopinacoidal cleavage) of sanidine. These crystals are twinned on the Carlsbad law, and recall similar ones in a dyke on Stakeley Moor, south of the Shap

* 'Bala Volc. Series of Caernarv.' (1889) pp. 22, 23.

Fell granite*. The whiter and finer-grained rock which crops out just to the eastward of the foregoing is probably only a marginal modification of the main mass. Here the plates of white mica are rarer, and the most striking feature is the occurrence of long narrow blade-like crystals of dark mica, precisely like some found on the margin of the Shap Fell granite and in the dyke on Potter Fell, which seems to be connected with that mass†.

A slide [842] of this Dufton Pike rock shows plenty of porphyritic quartz, in clear idiomorphic crystals with only a few glass-cavities or small inclusions of groundmass. Among the porphyritic felspars, a plagioclase with Carlsbad-, albite-, and pericline-twinning predominates. The light mica is perfectly clear and colourless, the dark decomposing with a green colour. Rarely the two are intergrown. Both micas recur in small flakes with a rough parallel disposition, and these must be regarded as part of the groundmass. An occasional hexagonal prism of apatite is seen. The ground of felspar and quartz is of the microcrystalline or "microgranite" type.

A specimen from a dyke north-west of Cuns Fell differs somewhat from the preceding, especially in the absence of white mica, and probably represents the usual type of the district [918]. The porphyritic crystals of quartz have their edges rather rounded, and are sometimes broken, but the fragments are not far separated. A flake of dark mica is sometimes enclosed in the quartz, as well as in the porphyritic felspars.

On the hillside north-west of the "Spring" in Ousby Dale the rock shows some remarkable modifications, which can be referred only to intense dynamic metamorphism. In the field it shows only a slightly different appearance from other examples of these quartz-felspar-porphyries, except that it has a general yellow iron-stained colour. A section, however, shows that a large part of the rock consists of colourless mica [1319]. The porphyritic felspars without losing their form are completely replaced by minute scales of this mineral, the scales in any one pseudomorph having a very general, though not uniform, orientation parallel to the length of the original felspar-crystal. Similar scales of mica occur in great quantity in the general mass of the rock, together with large flakes, which are rather ragged and wavy, and do not give very precise extinction between crossed nicols. The rounded and corroded porphyritic crystals of quartz are only occasionally cracked and broken. Dark mica is absent, but is perhaps represented by the larger flakes of colourless mica, each of which encloses a shapeless patch of limonite. Little flocculent patches of yellow ferruginous matter occur also in the groundmass. Except for these and the minute scales of mica, the ground consists of a clear microcrystalline mass of quartz and felspar, without trace of crystal outlines, and highly suggestive of recrystallization *in situ*. It is not easy to

* See p. 288 of this volume.
† See p. 277 of this volume.

distinguish the felspar from the quartz; the great majority of the grains are simple, but here and there one shows twin-striation. It will be noticed below that the diabase near this locality gives evidence of great crushing.

The large igneous mass on Thack Moor and the intrusions in Ousby Dale, apparently offshoots of it, belong to the same general type as the Dufton intrusive rock, but lack white mica. In all these rocks the closeness of the porphyritic crystals, obscuring the groundmass, gives a very crystalline appearance in the field or in hand-specimens.

Certain intrusive rocks, such as the large mass to the south of Cocklock Scar and some dykes, *e. g.* at Maiden Way in Ardale Beck, show a considerable departure from the foregoing and an approach to the characters of the lamprophyres described below. In hand-specimens they have a less crystalline appearance than the quartz-porphyries, and quartz is not recognized. The general aspect is that of some so-called porphyrites, the colour being brown with little stained felspar-crystals and facets of dark mica and augite. The slices [916, 922] bear out the idea of a transition to the lamprophyre type. Besides the greater abundance of dark mica, mostly undergoing a greenish alteration, we notice the coming in of abundant apatite and magnetite, and especially of augite in perfectly formed crystals, now completely pseudomorphed. The groundmass of these rocks is much decomposed, and it is difficult to decide whether any part of the free silica is original.

## 5. The Lamprophyres.

It would not be easy, and perhaps not very profitable, to attempt any such division of the "mica-traps" of the North of England as that between minettes and kersantites. A distinction founded on the crystallographic systems of the felspars is more futile than usual in this case, since those minerals are usually too far destroyed for recognition. Analysis might, of course, show the relative proportions of potash and soda present; but as this does not seem to bear any relation to the percentage of silica, &c.*, the character of the original felspar in any case would import little as regards the essential nature of the rock. The family-name "lamprophyre" is therefore sufficiently precise. In some of the rocks, as in Rosenbusch's "vosgesite," idiomorphic augite accompanies or to some extent takes the place of mica.

Like most lamprophyres, these rocks are very prone to decomposition by weathering agents, and are often impregnated with secondary carbonates. The freshest examples have a dark grey ground plentifully spangled with flakes of dark brown or nearly black mica, sometimes as much as an inch in diameter, but usually much less. In more altered specimens the mica takes a deep brown colour, with

* See Bonney and Houghton, Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 165.

submetallic lustre, and the groundmass, also stained with brown, has a dull appearance. Visible porphyritic felspars are found, but only very sparingly. The boundaries are often rounded, as if by magmatic corrosion. Occasionally a crystal of orthoclase shows a quite glassy lustre, but the felspars are usually dull and semi-opaque. Certain rocks, such as the large dyke in Dry Sike and the boss-like mass in Swindale, enclose grains of quartz of considerable size, the boundary rounded, or rarely with indications of the dihexahedral form. The grains are commonly surrounded by a thin coating of a dark green substance.

Included fragments of partially vitrified grit, &c., are found in the large Swindale boss. Vesicles, usually filled by calcite, also occur.

The mica of these rocks is a brown biotite in tabular crystals more or less regularly bounded in the usual pseudo-hexagonal fashion. The plane of the optic axes is perpendicular to the basal cleavage and parallel to the clinopinacoid. The bisectrix makes a very sensible angle (3° or 4°) with the normal to the basal cleavage, so that in cross-sections of the flakes the frequent twin-lamellation parallel to the base is easily detected. Indeed, owing to the pleochroism, this can be seen with a single nicol. Juxtaposition-twins parallel to the prism-plane * are also common. In almost every case the deep brown colour characteristic of biotite in most rocks is here confined to the border of each flake, the interior being much paler, or, indeed, for vibrations parallel to the $\alpha$-axis, sensibly colourless. Whether this is an original zonary structure or a result of internal bleaching is not quite clear. Rosenbusch † apparently takes the former view for the mica of lamprophyres generally. It is noticeable that, although in cross-sections of flakes the border is usually very sharply defined, basal sections show a more gradual passage from dark to pale. Streaks of darker colour, following the basal cleavage-direction, are occasionally seen passing through the pale interior, and this seems rather to favour the idea of secondary bleaching. Much rarer than the dark border is a dark nucleus, always sharply defined by crystallographic planes, with a paler margin [915]. The dark and pale mica-substances in these rocks possess very different powers of birefringence. Rough measurements gave the figures 0·06 and 0·04, which, according to Lévy and Lacroix, correspond to brown biotite and colourless meroxene respectively.

Resorption-phenomena, with a separation of iron ore, are sometimes seen on the edge of a flake [914]. Again, owing to mechanical forces, the flakes have in some cases yielded along "gliding-planes," as in the artificial twin-lamellæ produced in calcite, &c. The gliding-planes do not coincide with the basal cleavage [914]. The mica occasionally encloses grains of magnetite, or is penetrated by slender hexagonal prisms of apatite. Again, the edge of a flake

* See Lévy & Lacroix, 'Minéraux des Roches' (1888), p. 239, fig. 137.
† 'Mikr. Physiogr. d. mass. Gest.' 2nd ed. (1887) p. 310.

sometimes shows numerous very minute needles (? rutile) arranged along the basal cleavage, parallel to the sides of the hexagon [915]. The most characteristic inclusions, however, are very minute crystals, probably of zircon, which are invariably surrounded by strongly pleochroic halos. These halos are very conspicuous, reproducing in the pale interior of the flakes the dark colour of the brown border. A common decomposition-product of the mica is calcite, or possibly dolomite, often forming lenticles or plates along cleavage-planes [445] *.

In addition to mica, some at least of the rocks, such as those of Dry Sike, have contained augite. The mineral is completely destroyed, but the pseudomorphs show the characteristic octagonal cross-section [915]. Original magnetite is not plentiful in our specimens. Most of the slides contain little crystals of pyrites, which moulds the biotite, and is perhaps a secondary mineral. The porphyritic felspars, when recognizable, are seen to be orthoclase and a plagioclase with rather low extinction-angles ; but most of the felspars are deeply altered, and some are entirely replaced by calcite [914].

The quartz-grains, already alluded to, present in section an ovoid outline, or, more rarely, rounded crystal-forms [915]. The bordering ring is seen to consist of minute crystals of fibrous hornblende, pale green in a slice. These are partly moulded by the quartz, while, on the other hand, they are not distinctly separated from the mass of the rock. The appearances suggest a reaction between the quartz-grains and a corroding magma, and recall the primary quartz-grains with a coating of augite-granules described by Iddings † in certain basalts.

The groundmass of these lamprophyric rocks is for the most part too much decomposed for precise study. It has probably been microcrystalline throughout. In some cases the mica seems to belong to two generations, of which the later, in smaller flakes, forms part of the ground [445, 446 *a*]. The bulk of the ground has consisted of felspars, which sometimes sank almost to microlithic dimensions [915]. The most abundant decomposition-products are calcite and quartz. Where these occur collected in distinct patches, the quartz is often idiomorphic and moulded by the calcite.

## 6. Basic Intrusive Rocks.

The chief intrusive rocks of basic character in the district are the diabases of Cuns Fell. These show considerable variations in texture. In the coarse-grained type it is easy to recognize the rectangular crystals of striated felspar and the dark green cleavage-faces of augite, or, again, black lustrous plates of hornblende. As will appear, this last mineral is not an original constituent. In the

* This is the slide figured in Teall's 'Brit. Petrogr.' pl. xxxii. fig. 2.

† Amer. Journ. Sci. (3) vol. xxxvi. (1888) p. 208; Bull. U.S. Geol. Surv. (1890) No. 66.

specimens of finer grain the individual minerals are scarcely to be detected by the unaided eye.

In mineralogical constitution the Cuns Fell diabases present no special peculiarities. Apatite prisms occur plentifully, though only locally [924]. Crystals and rods of magnetite are always present, but ilmenite is not found. The bulk of the rocks, now considerably decomposed, has been built of felspar and augite, the former in idiomorphic crystals, the latter mostly in ophitic or semi-ophitic plates. The Cuns Fell rock has been termed a gabbro, but its structure is that of a typical diabase, with even an occasional approach to the doleritic type in the development of a few shapeless felspars of later consolidation. The ordinary felspars show albite- and pericline-twinning, and, so far as can be judged from their extinction-angles in rock-slices, may be referred to the border-land between andesine and labradorite. The augite, when unaltered, is colourless in sections, but this mineral is frequently quite destroyed, the common decomposition-products being pale-green delessite, clear quartz, calcite, and opaque dust (kaolin?). It is, however, frequently replaced by hornblende; sometimes pale greenish-yellow with a fibrous structure and inclusions of secondary magnetite, but more usually clear yellow-brown and pleochroic with a compact structure and good prismatic cleavage. There can be no doubt that this mineral is derived from the augite: the process of conversion, beginning at the margin and along cleavage-cracks, is seen in various stages [925]. The hornblende, as in some other rocks of this kind, gives rather high extinction-angles ($c\,\gamma =$ about $20°$); and it is to be noticed that, in an augite-plate partly transformed into hornblende, the extinctions for the two minerals are, as usual, on the same side of the vertical axis.

Another common feature of these diabases is the occurrence of a fringe of colourless hornblende growing in crystallographic relation with the crystal-plates, but outside them, and clearly formed at the expense of other minerals, to which it presents a very ragged edge. Such fringes surround not only the uralitic hornblende, but also patches of delessite which are evidently the relics of vanished augite. The order of the several changes indicated is therefore:—(i.) partial or total replacement of augite by hornblende, the uralitic hornblende being perhaps a stage in the conversion to the compact; (ii.) growth of colourless hornblende-fringes about both hornblende and augite, this proceeding concurrently with alterations in the felspar, &c.; (iii.) conversion of much of the remaining augite into delessite and other weathering-products.

The hornblendic rocks examined are from the west and north-west sides of Cuns Fell. On the south-east side, near its junction with the Skiddaw Slates, the diabase takes on a finer grain, and, in particular, the felspars occur in long narrow prisms only once or twice twinned on the albite law, without, however, any marked parallelism of disposition [928]. At Dale Beck the diabase has a very crushed schistose appearance, and a slice shows that it consists mainly of calcite and delessite [926]. Another specimen

from this neighbourhood (marked 'Spring' on the six-inch map) has in addition a quantity of finely crystalline to cryptocrystalline silica, sometimes with a spherulitic structure [1320]. In the field this rock presents a singular appearance owing to the numerous parallel narrow veins of calcite which traverse its dark mass.

A specimen of diabase from a dyke in Rake Beck differs in some respects from the Cuns Fell rocks. The felspar seems to approach typical labradorite, and encloses occasional crystals of light-brown sphene [923].

At Deep Slack Wood, close to the exposure of the basic lavas of Melmerby, occurs a fresh-looking, finely crystalline dolerite, very different from the neighbouring rocks. It consists largely of little lath-shaped striated felspars, besides a few larger individuals with broader lamellæ and an occasional shapeless felspar with strong zonary structure, of the kind so characteristic of doleritic rocks [1323]. The augite forms ophitic plates each enclosing many of the small felspars ; magnetite occurs interstitially among the felspars in some abundance. The felspars are always quite clear ; much of the augite is fresh, but part is replaced by brown and green decomposition-products, and a similar green substance fills the few scattered vesicles. The rock is unlike any known Ordovician lava or intrusion in the district, and suggests a dyke of much later age, post-Carboniferous or even perhaps Tertiary.

## 7. Quartzite of Roman Fell.

An interesting modification of the Carboniferous sandstone is represented by some of Mr. Marr's specimens collected on Roman Fell. The sandstone here has been locally converted into a compact vitreous-looking rock by the deposition of secondary quartz.

Under the microscope [911] the rock exhibits all the characters of a quartzite such as those of Hartshill and the Stiperstones *. The original grains are almost all well rolled. Quartz largely predominates, mostly with a very dusky appearance due to crowds of inclusions, often ranged in parallel lines. A few of the quartz-grains are composite. In much less quantity occur weathered felspar-fragments and little rounded pieces of a microlithic andesite. The interstitial quartz occurs entirely as a "secondary enlargement," easily distinguished from the original grains, with which it is in crystalline continuity, by its clear appearance. More rarely the felspar grains show a similar secondary growth, a phenomenon observed elsewhere by Van Hise and others. It occurs both on orthoclase and plagioclase-fragments.

* Compare, *e. g.*, the Lickey quartzite figured in Mr. Teall's 'Brit. Petrogr.' plates xlv., xlvi.

## APPENDIX II.—*On some* CEPHALOPODA *from the* CROSS FELL INLIER. By A. H. FOORD, Esq., F.G.S.

1. ORTHOCERAS, *cf.* ELONGATOCINCTUM, Portlock.

Portlock, 'Geology of Londonderry,' (1843) p. 372, pl. xxvii. figs. 2 *a*, 2 *b*. Blake, 'British Fossil Cephalopoda,' pt. i. (1882) p. 119, pl. xiii. figs. 7, 8, 8 *a*.

*Description.* An elongated, cylindrical species with a very slow rate of increase: the septa, as seen in fragments, distant from each other rather less than one-third the diameter of the shell. The siphuncle nearly central. The test ornamented with regular, transverse, thread-like striæ, which do not appear to undulate; about nine of them occupy the space of a line. Abundant in the limestone of Keisley, near Dufton.

*Remarks.* This is probably the species referred to by Profs. Harkness and Nicholson * under the name of *Orthoceras vagans*, Salter. The present species differs, however, from the latter (as interpreted by Prof. Blake) in its more approximate septa, and in the well-defined character of the ornaments of the test, whereas Salter's species is described as smooth (Salter †) or showing only lines of growth (Blake ‡). All the specimens are more or less covered by the matrix, but the ornaments of the test are shown on several of them.

The present species differs from Portlock's in respect of the septa, which are wider apart than they are stated to be in his species. *Orthoceras sodale*, Barrande §, presents some resemblance to the present form in its slow rate of increase, the position of the siphuncle, and the surface-ornaments; but the septa are more remote in *O. sodale*, which is also a larger and more robust shell than the one here described.

There appears to be another species associated with this one in the same matrix, but it is too fragmentary for description.

2. ORTHOCERAS, sp.

*Description.* An eroded fragment of a large *Orthoceras* from the *Staurocephalus* zone of Swindale is too imperfect for specific identification. The four chambers preceding the body-chamber are alone preserved. The shell may have been cylindrical or possibly elliptical in section; but the weathering it has been subjected to has destroyed its original form, causing one side to be flat while the other remains rounded. The septa are deeply concave; rather distant from each other, *i. e.* about seven lines apart where the diameter of the cast is about 1 inch 10 lines. The last two septa are, however,

* Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 461, 'On the Strata and their Fossil Contents between the Borrowdale Series of the North of England and the Coniston Flags.'

† In Sharpe, 'On the Geology of Oporto,' Quart. Journ. Geol. Soc. vol. v. (1849) p. 153.

‡ 'British Fossil Cephalopoda,' pt. i. (1882) p. 141.

§ 'Syst. Sil. de la Bohême,' vol. ii. pt. iii. (1874) p. 453, pl. ccccxvii. (excl. figs. 12, 13).

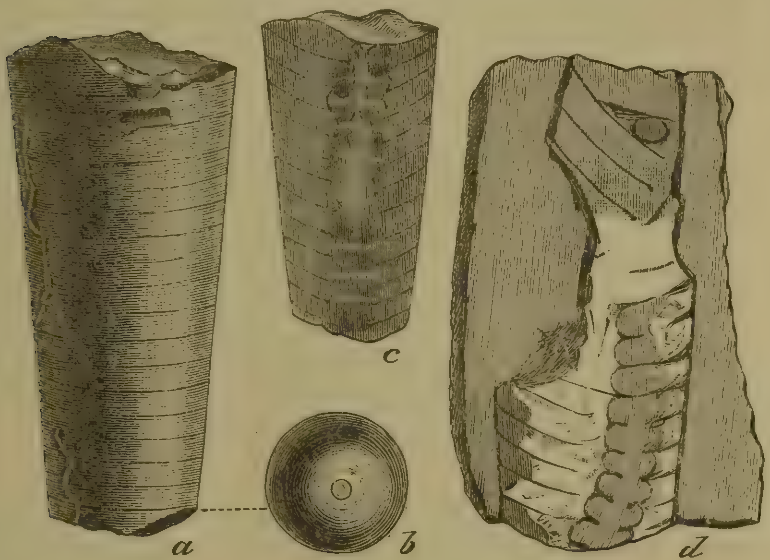
scarcely 6 lines apart, the diameter here having increased to about 2 inches. Two sections have been made, the one transverse, the other longitudinal, but without disclosing any trace of the siphuncle, which must have been contained in the part removed by weathering; if so, it could not have been far from the margin. No trace of the test exists.

*Remarks.* The general features of this fossil recall those of *Orthoceras ludense*, J. de C. Sow. (=*O. columnare*, Boll, *O. temperans*, Barr.), from the Upper Silurian rocks of Britain, Sweden, Bohemia, &c., and in its distant septa it is also comparable with *Orthoceras omissum*, Blake *. Both *O. ludense* and *O. omissum*, however, are found upon a much higher horizon than the present fossil.

3. Orthoceras pusgillense, sp. nov.

*Description.* Several fragments of the septate part of a species with a bulbous siphuncle were collected in the *Corona*-beds at

*Orthoceras pusgillense.*




*a*, cast, showing septa; *b*, base of septum with siphuncle; *c*, polished section; *d*, polished section, showing siphuncle pushed out of position.

Pusgill. The shell is cylindrical when uncompressed, and tapers somewhat rapidly, that is, at the rate of about 1 in $7\frac{1}{2}$, in a fragment 2 inches in length. The septa are very numerous, being about $1\frac{1}{2}$ lines distant from each other where the diameter of the shell is 11 lines; they are shallow, and are pierced by a nearly central siphuncle, having beaded segments which have a width equalling nearly one-fourth the diameter of the shell. The test is quite smooth. Some of the specimens have been crushed laterally

* 'British Fossil Cephalopoda,' pt. i. (1882) p. 169, pl. xv. figs. 9, 9 *a*.

in such a manner as to displace the siphuncle, bending it and forcing it towards the opposite side. No estimate can be made of the size of this fossil, the body-chamber being absent in all the specimens collected.

Three crushed and weathered fragments from the same locality and horizon, but somewhat larger than those just described, have similarly close-set septa and a beaded siphuncle, and they most probably belong to the same species.

The present form agrees with *Orthoceras* (? *Actinoceras*) *mendax*, Salter *, in the close proximity of its septa, but differs therefrom in its more rapid rate of tapering. The test not being preserved in the specimens from the Durness Limestone, upon which Salter's species was founded, no comparison can be made between the two species as regards this feature. It will be better therefore to regard it, provisionally, as new.

4. Cyrtoceras (?).

Fragmentary casts of the peripheral part of a small curved shell from Roman Fell exhibit septal characters similar to those of *Cyrtoceras* (*Phragmoceras*, Portl.) *inæquiseptum*, Portlock †, sp., from the Bala Beds of Desertcreat, Co. Tyrone. These specimens are too imperfect for description.

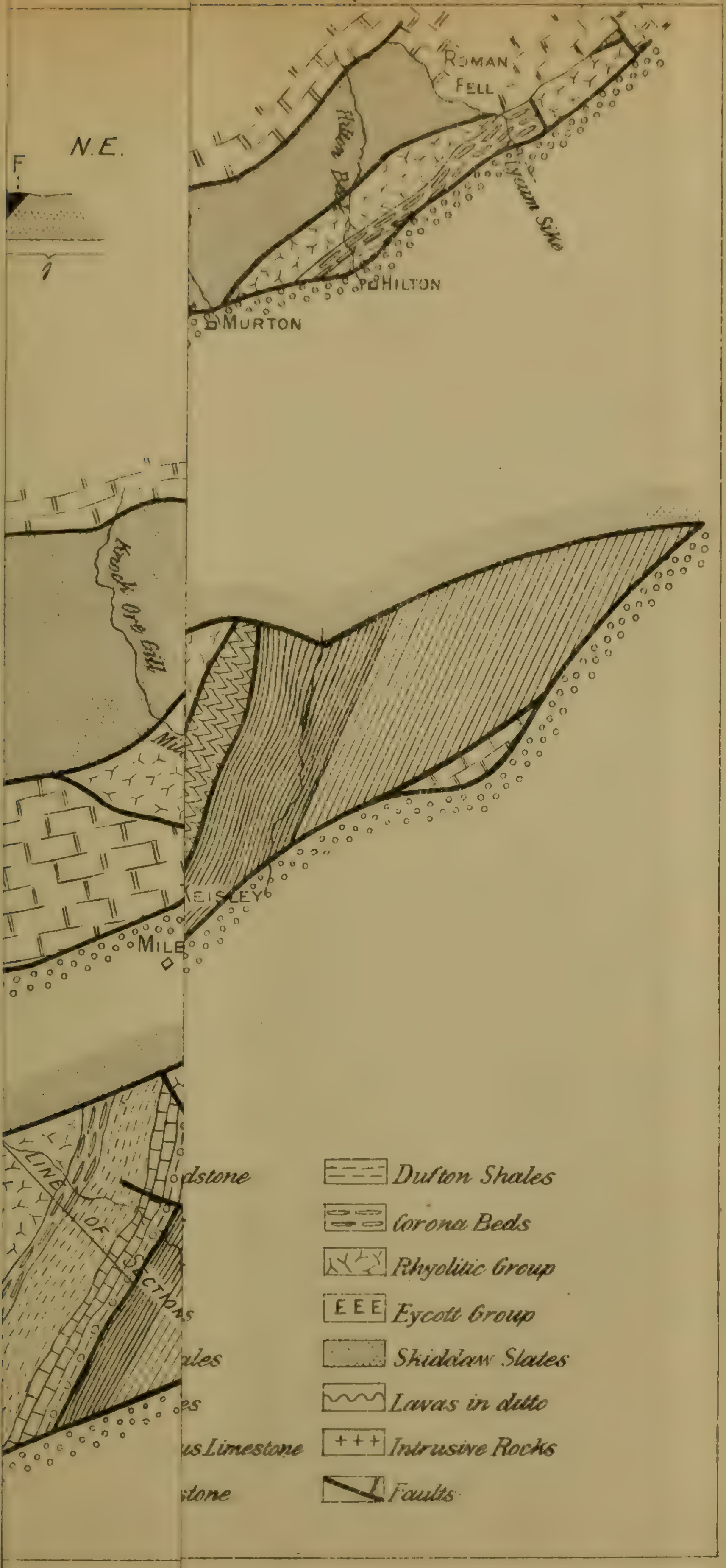
## Discussion.

Prof. Boyd Dawkins said that the case cited by Mr. Marr of a fault having been in course of development at different geological periods is by no means an isolated example. Many faults show signs of movement at different ages. The Thousand-yards Fault, for example, passing up the valley of the Irwell to the N.W. of Manchester, shows a throw of 1000 yards in the Coal-measures, but very much less in the Permian and Triassic strata thrown down to the north. With regard to the phyllites, the phyllites of the Isle of Man form a link between the clay-slates on the one hand and mica-schist on the other.

Dr. Hicks asked whether the term "Bala," as used by the Authors, included any typical Llandeilo rocks; or whether it was confined, as he thought it ought to be, to such rocks as are classed under that name in North Wales. The section on the wall appeared to show a continuous succession from the Skiddaw Slates to Upper Silurian. He would be glad to know whether there was clear evidence of continuous deposition in the area generally; and whether there was no evidence of a break between the beds which had been recognized by Mr. Goodchild as of Tremadoc age and the overlying Arenig beds.

With regard to the faults shown on the map, he would like some explanation as to how the Authors accounted for the fact that they appeared repeatedly to cross the higher beds without affecting the

* Quart. Journ. Geol. Soc. vol. xv. (1859) p. 374, pl. xiii. fig. 24, *a*, *b*.
† 'Geology of Londonderry' (1843), p. 382, pl. xxviii. A. figs. 4 *a*, 4 *b*.


N.E.
F
ROMAN FELL
Hilton Beck
Lycum Sike
HILTON
MURTON
Knock Ore Gill
EISLEY
Dufton Shales
Corona Beds
Rhyolitic Group
EEE
Eycott Group
Skiddaw Slates
Lavas in ditto
+++
Intrusive Rocks
Faults

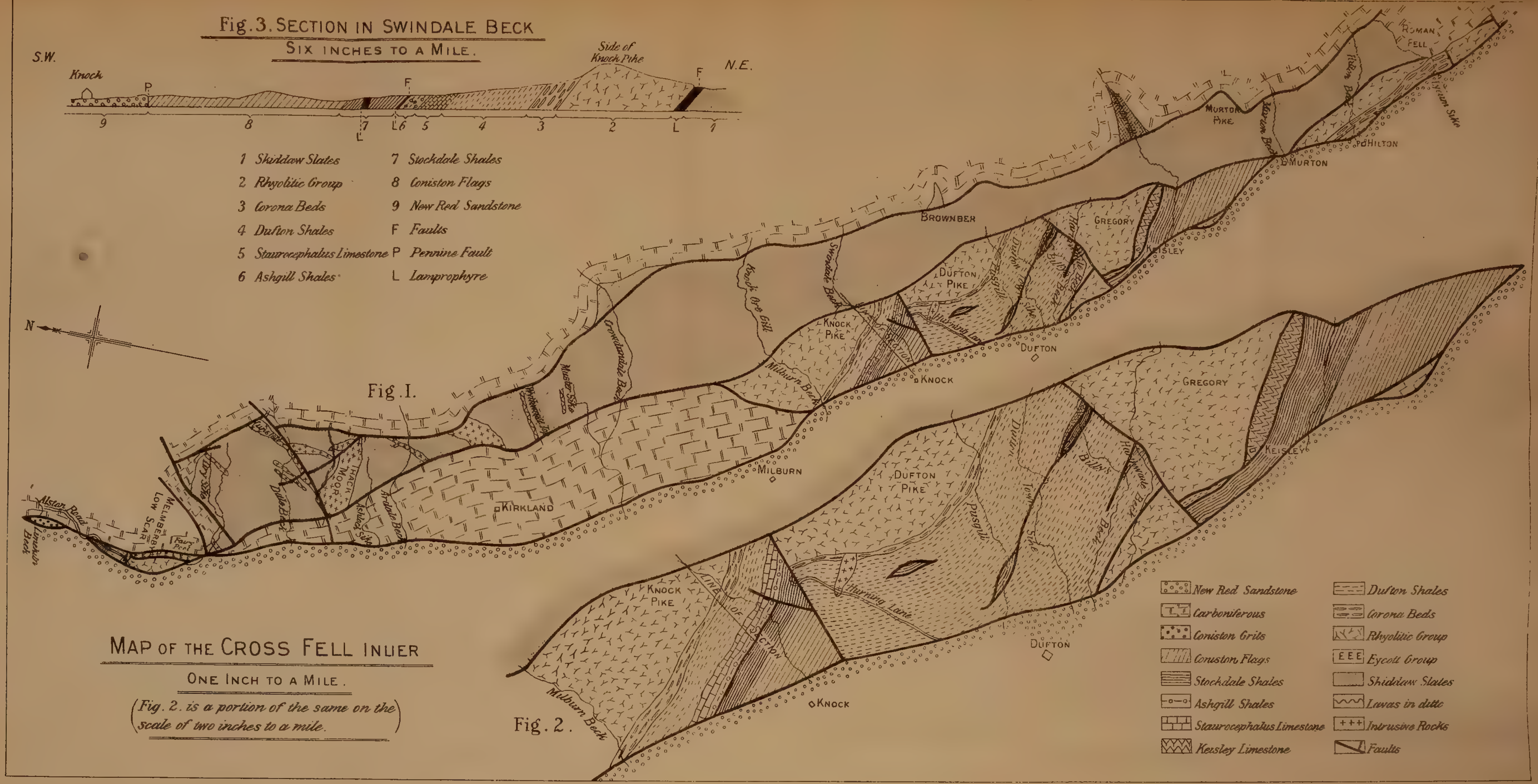


Fig. 3. SECTION IN SWINDALE BECK
SIX INCHES TO A MILE.
S.W.
N.E.
Knock
Side of Knock Pike
P
F
F
L
L
9 8 7 6 5 4 3 2 1
1 Skiddaw Slates
2 Rhyolitic Group
3 Corona Beds
4 Dufton Shales
5 Staurocephalus Limestone
6 Ashgill Shales
7 Stockdale Shales
8 Coniston Flags
9 New Red Sandstone
F Faults
P Pennine Fault
L Lamprophyre
N
Fig. I.
ROMAN FELL
MURTON PIKE
HILTON
MURTON
BROWNBER
GREGORY
KEISLEY
DUFTON PIKE
KNOCK PIKE
DUFTON
KNOCK
MILBURN
KIRKLAND
Alston Road
MELMBERBY LOW SCAR
TRACK MOOR
Swindale Beck
Knock Ore Gill
Crowdundle Beck
Milburn Beck
Dufton Town Sike
Billy's Beck
Pusgill
Hurning Lane
Murton Beck
Fig. 2.
GREGORY
KEISLEY
DUFTON PIKE
KNOCK PIKE
LINE OF SECTION
DUFTON
KNOCK
Milburn Beck
Pusgill
Dufton Town Sike
Billy's Beck
Hurning Lane
New Red Sandstone
Carboniferous
Coniston Grits
Coniston Flags
Stockdale Shales
Ashgill Shales
Staurocephalus Limestone
Keisley Limestone
Dufton Shales
Corona Beds
Rhyolitic Group
Eycott Group
Skiddaw Slates
Lavas in ditto
Intrusive Rocks
Faults
MAP OF THE CROSS FELL INLIER
ONE INCH TO A MILE.
(Fig. 2. is a portion of the same on the scale of two inches to a mile.)

underlying and adjoining older beds. He thought it would be well if the Authors could supply further evidence bearing on the direction of the earth-movements which had produced such results, and on the physical changes generally which had affected the area under discussion.

Mr. Rutley asked what was the breadth of the dykes represented in the section: and whether, in any case, they were found to follow the directions of faults. He approved of the application of the term "lamprophyre" to these rocks.

Mr. Hudleston said that the district was one of the most interesting from a geological point of view in England, and he expressed regret that so few persons who had been over the ground were at the meeting. It would have been an advantage to have heard Mr. Goodchild's views. Nevertheless, they had seen that it was possible to criticize effectually without special local knowledge. An intimate acquaintance with this Inlier would help to explain some of the difficulties experienced in the geology of the Lake District; the distribution of the Eycott-Hill type of rock was a case in point. There could be no better proof of the importance of the argument from palæontology than the correlation of the Dufton Shales with the Keisley Limestone, so unlike in lithological character. Perhaps the explanation of that difference as having been mainly due to subsequent deformation was open to some doubt. There could be no question as to the value and general interest of the paper.

The Chairman congratulated the Authors on the reception of their paper by the meeting, and pointed out that contributions of this class, in which stratigraphical details were illustrated by careful palæontological research, had become comparatively less common in the Society's Journal than they formerly were, although the value of such papers, as was well illustrated by the present example, had by no means diminished.

Mr. Marr, in reply, explained that the term "Bala" was used by them as synonymous with Caradoc, so that their Lower Bala of this district was not Llandeilo. He remarked that the apparent conformity between the Skiddaw Slates and the Rhyolitic Group was illusory, and that the newer beds abutted discordantly against the fault. He justified the absence of cross-faults in the Skiddaw Slates on the ground that the faults were only drawn where actually observed, but pointed out that Sedgwick had long ago shown how it was perfectly possible to get faults which did not affect older rocks in immediate vicinity to the newer rocks which were profoundly affected. He stated that Mr. Harker had in his appendix entered into some detail concerning the lamprophyres.

He observed that the Authors had not given any definite explanation of the difference between Keisley Limestone and Dufton Shales, as evidence for such was not to be gained from this isolated region. All that they maintained was that the Keisley Limestone and Dufton Shales were referable to the same subdivision, which was older than the *Staurocephalus*-Limestone and newer than the *Corona*-beds.

## 28. *On a* SPHERULITIC *and* PERLITIC OBSIDIAN *from* PILAS, JALISCO, MEXICO. By FRANK RUTLEY, Esq., F.G.S., Lecturer on Mineralogy in the Royal College of Science, London. (Read April 22, 1891.)

[PLATE XVIII.]

THE specimen upon which the following observations were made is a greyish-green or leek-green obsidian with a waxy lustre, containing numerous deep brownish-red spherulites, ranging from the size of peas to smaller dimensions. It was collected by Dr. A. E. Foote, to whose kindness I am indebted for it.

Under the microscope the thin section shows banded and perlitic structures, the former being delicate and even, while the latter is developed with a perfection which I have never seen equalled. Each perlitic area, as a rule, includes several centres, sometimes five or six, or more, around which perlitic structure has been developed (Pl. XVIII. fig. 1). A similar complex perlitic structure has already been noted in certain dacites by Prof. Judd *. The glass of the obsidian contains numerous globulites and longulites, which are densely crowded together along the fluxion-banding.

The perlitic fissures appear in all cases to have been filled up with siliceous matter, showing, in some instances, minute crystalline rods or fibres, passing from the walls towards the middle of the fissure, where a distinct line of arrest parallel to the walls may be seen. This secondary crystalline matter exhibits double refraction, so that the perlitic structure appears brightly illuminated and in strong relief against the glass of the obsidian, when viewed between crossed nicols (Pl. XVIII. fig. 2).

It is only here and there, however, that these somewhat regular growths from opposite walls of the cracks are to be seen. At times the minute crystalline rods or fibres occur in little divergent groups, and occasionally the growth has also passed from the walls of the crack into the glassy substance of the obsidian, thus giving rise to very minute pellets or spherulites of chalcedony which, when the section is viewed between crossed nicols, cause the perlitic fissures to appear broader than they do in ordinary light. These divergent groupings or spherulitic bodies are very minute as a rule, but in one or two instances, where they are sufficiently large to admit of the determination of their optical sign, they are found to be positive. The longulites which follow the direction of the fluxion-banding seem to pass through the material which has sealed up the perlitic fissures; but this appearance is, of course, deceptive, and is due to the inclination of the cracks to the plane of section, a longulite when partially overlying or underlying an obliquely-inclined crack appearing to penetrate the transparent matter with which the latter is sealed.

* See 'The Volcanic Rocks of the North-east of Fife,' by J. Durham, with an appendix by Prof. J. W. Judd, Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 429.

In addition to the ordinary circumferential perlitic fissures, radial fissures may sometimes be observed, but they do not pass uninterruptedly through a series of circumferential cracks, being merely continuous from one crack to the next.

The dark brownish-red spherulites appear reddish or yellowish brown in thin section, when viewed in transmitted light. Their outlines are sharply defined, and the perlitic structure accommodates itself to their boundaries. From this, and from the fact that no trace of perlitic structure is to be discovered within them, it is evident that the spherulites were formed before the perlitic structure was developed. It might be urged that molecular rearrangement (induced during the formation of the spherulites) might have obliterated any perlitic structure, had such existed, in the areas now occupied by those bodies; but such an hypothesis cannot be entertained, since the delicate fluxion-banding of the obsidian is clearly visible—passing uninterruptedly through the spherulites; and it is evident that, since this structure is preserved, so also would the perlitic structure have been, had it been developed prior to the formation of the spherulites.

The sequence of the structures in this rock admits of no question. The fluxion-banding was developed first, the spherulites were subsequently formed, then perlitic structure was set up, and these fissures were finally sealed by the introduction of chalcedonic matter.

At the point or points (for there are sometimes more than one) from which the spherulites originated, a confused microcrystalline structure may usually be seen, and from this point, or from these points, divergent bundles of delicate fibres or crystalline rods have been developed. Within these fasciculi, finely puckered or wavy transverse banding may be noticed, indicating slight pauses in the crystalline growth, and occasionally the fluxion-bands appear to have offered a temporary check to the development of crystalline bundles which were growing approximately at right angles to the direction of the fluxion-bands. In such cases the band which caused the check has served as the base from which a fresh crop of crystalline bundles has grown (as shown in Pl. XVIII. fig. 3), and in one instance the development of a spherulite has been completely arrested along a fluxion-band, as represented in Pl. XVIII. fig. 4.

In another case a spherulite has been developed prior to the formation of a similar but larger spherulite which encloses it. Some of the spherulites envelop small crystals of triclinic felspar, as shown in the upper half of fig. 4, Pl. XVIII. They present the appearance either of imperfectly-developed or of corroded crystals, probably the former, and delicate fringe-like processes from the enclosing spherulite may be seen penetrating them for a short distance beyond their margins.

Fig. 5, Pl. XVIII., represents globulites, longulites, and minute pellets of chalcedony occurring in the glassy portions of the rock.

It seems very probable that this obsidian has been subjected to hydrothermal agency since its solidification and the development of its perlitic structure. The siliceous matter with which the perlitic

fissures are filled, and which also occurs in the obsidian itself, either fringing the perlitic cracks or disseminated in small spherulitic bodies, indicates this, while the numerous globulites which are present are probably due to a like cause. Whether solfataric action gives rise to the formation of globulites in vitreous rocks is a question which has not, I think, as yet, been demonstrated; but I may mention that a specimen of spherulitic obsidian, collected by Mr. G. F. Rodwell some years ago in the crater of Vulcano at a point where a powerful jet of steam issued and where sulphur was deposited, no longer presents the bright glassy lustre so characteristic of fresh obsidians, but appears perfectly dull and has a stony instead of a glassy aspect.

In thin section under the microscope the rock is seen to be traversed by a network of fine, irregular cracks, and its loss of lustre is found to be due to the development of innumerable globulites, as shown in fig. 6, Pl. XVIII. The distinctness of the spherulitic structure has also suffered considerably, owing to the devitrification which, in this case, appears very probably to have been engendered by the action of steam.

## EXPLANATION OF PLATE XVIII.

Fig. 1. Spherulitic and perlitic obsidian from Pilas, Jalisco, Mexico, showing complex perlitic structure and delicate fluxion-banding. × 18 linear. Ordinary transmitted light.

2. Ditto, showing perlitic fissures filled with doubly-refracting siliceous matter (chalcedony). × 140 linear. Crossed nicols.

3. Ditto, showing portion of a spherulite, in which the growth has been temporarily arrested along a fluxion-band, the latter having served as a basis for subsequent growth of the spherulite. × 18 linear. Crossed nicols.

4. Ditto, showing portion of a spherulite, the development of which has been permanently arrested along a fluxion-band. This figure also shows that the perlitic structure does not traverse the spherulite, but that it accommodates itself to the contours of the latter. The fluxion-banding passes through the spherulite. × 18 linear. Ordinary transmitted light.

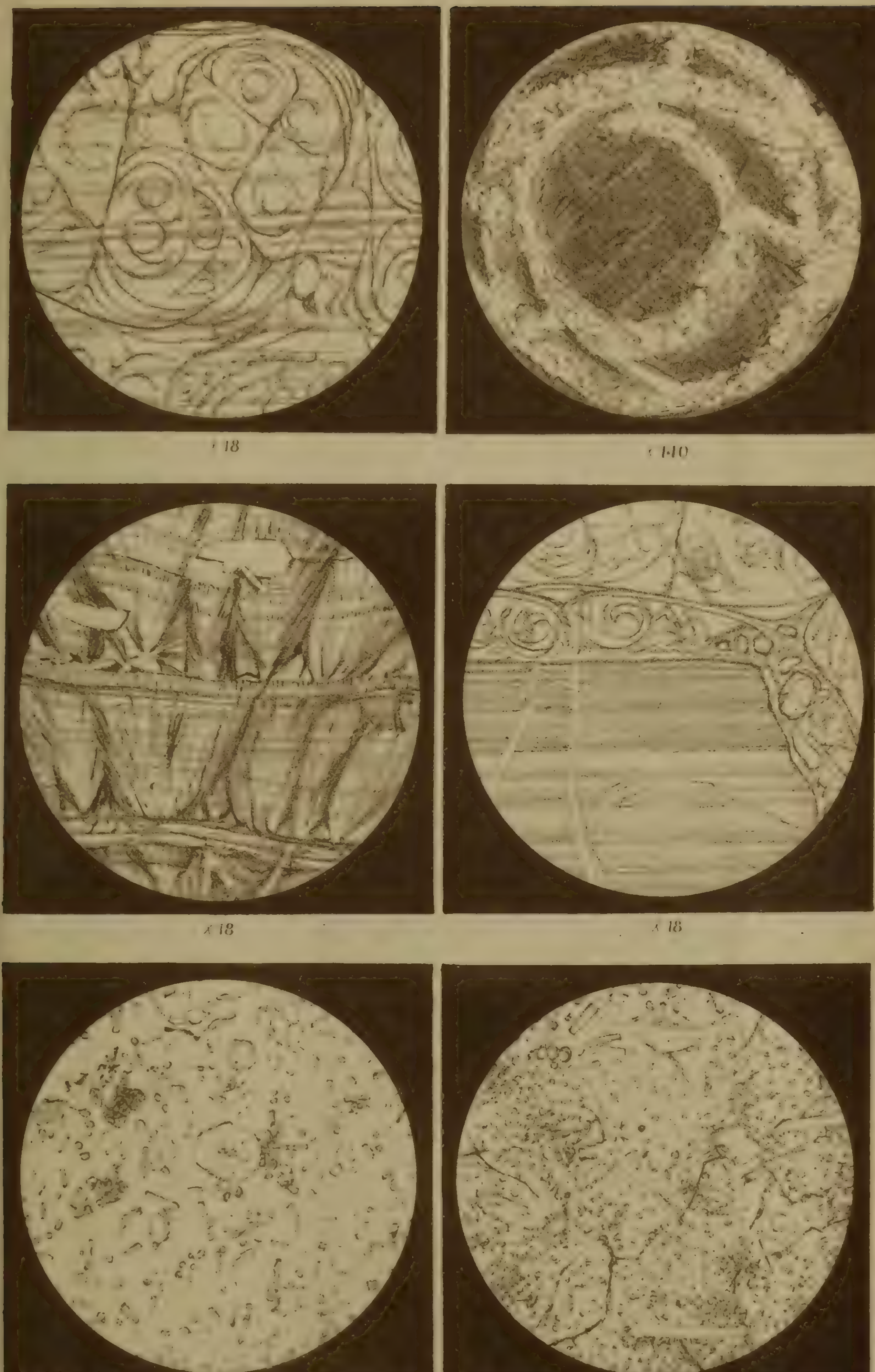
5. Ditto, showing globulites, longulites, and pellets of chalcedony, occurring in the glass of the obsidian. The fluxion-banding passes diagonally upwards from left to right in this figure. × 250 linear. Ordinary transmitted light.

6. Devitrified spherulitic obsidian from the crater of Vulcano, Lipari Is. Collected at a point from which a powerful jet of steam was issuing. This obsidian is completely, or almost completely, devitrified by the development of globulites. In many parts of the section the globulites are much more densely crowded than in the portion here figured. × 250 linear. Ordinary transmitted light.

## Discussion.

Prof. Judd asked whether the Author had any information as to the locality of this interesting specimen, and especially as to its relation with any of the well-known varieties of Mexican obsidians.

Mr. G. F. Kunz stated that the locality in Jalisco was about one hundred miles west of Mexico city, and one hundred and fifty miles north-west of Pachuca ("Navajas"), the Hill of Knives.



1 ×18 — 2 ×140 — 3 ×18 — 4 ×18 — 5 ×250 — 6 ×250

Frank Rutley del. F. H. Michael lith. Mintern Bros. imp.

[illegible] OBSIDIAN [illegible] MEXICO
[illegible] VULCANO [illegible]

Mr. Rutley, in reply to Prof. Judd's remarks, stated that, although the specimen resembled a pitchstone in lustre, he was inclined to believe this due to partial devitrification, as indicated in the paper. It was, however, difficult at times to say positively whether minute bodies, such as globulites, longulites, &c., present in a vitreous rock were developed at the time of solidification or at a subsequent period; but he was disposed to regard them in this case as secondary products. It was fortunate that Mr. Kunz was present and able to describe the locality from which the specimen was derived.

# 29. *On some of the* Melaphyres *of* Caradoc, *with* Notes *on the* Associated Felsites.

By Frank Rutley, Esq., F.G.S., Lecturer on Mineralogy in the Royal College of Science, London.

(Read June 24, 1891.)

[Plate XIX.]

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## I. Introduction.

While staying at Church Stretton during the autumn of last year I paid several visits to Caradoc Hill for the purpose of acquiring some information concerning the nature of the felsites which occur there. Many chips were collected, not only of felsites but also of basic eruptive rocks, and sections were subsequently cut from those specimens which seemed likely to show points of interest.

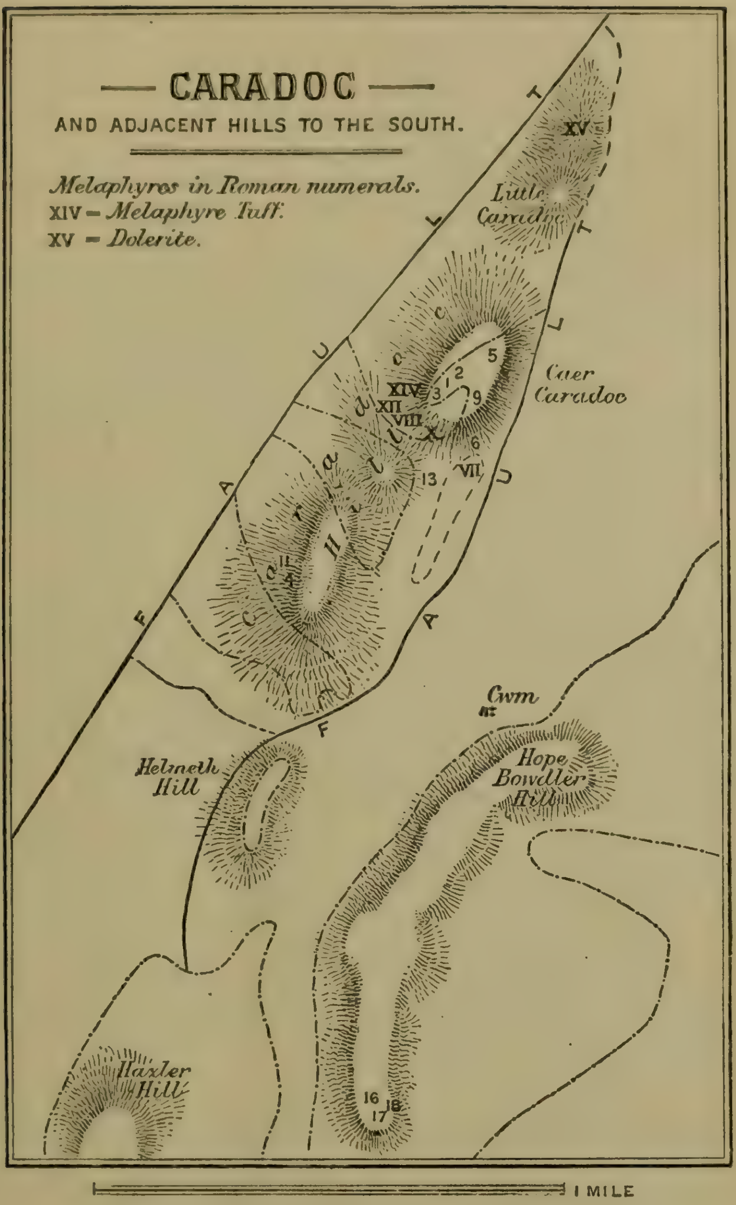
Although the structural geology of this area has been investigated by several observers since the publication of the Geological-Survey map, no account of the microscopic characters of these rocks appears, hitherto, to have been published. In the following paper an attempt is made to supply this deficiency to a certain extent, but, since the time at my disposal permitted the collection of specimens from only a limited portion of Caradoc Hill, chiefly from different spots situated to the south and south-west of the Camp, there remains much ground which the present paper leaves untouched.

The points from which the different specimens were derived are marked with some approximation to truth on the accompanying outline map, on which the geological boundaries laid down on the published Survey map are indicated. The Arabic numerals refer to the numbers with which the specimens of felsite, derived from those spots, were ticketed, while the Roman numerals denote basic eruptive rocks. The numbering of the specimens and sections bears no relation to any sequence in the field or relation of the rocks to one another, and has merely been retained to avoid any possible source of error from re-labelling.

## II. The Melaphyre Series.

The following are descriptions of certain selected types of the Melaphyre Series.

No. XII. S.W. side of Caer Caradoc, near the top of the hill. Altered vesicular basalt-glass. (Melaphyre.)




Felsites (Rhyolites) 1, 5, 6, and 9:—more or less spherulitic and vesicular.
" " 2, 3:—vesicular, with elongation of vesicles.
" " 4, 11, 13, 16, 17:—perlitic.
" " 18:—Rhyolite tuff.

A dark bluish-grey, vesicular rock, the vesicles being mostly filled with pale greyish-white or dark green substances. The weathered surfaces are rusty-brown and the amygdules at the surface have usually decomposed, leaving empty pores which impart a somewhat scoriaceous aspect to the rock. Under the microscope, in thin section, it is seen to consist of once glassy matter, now more or less devitrified by the development of microliths and globulites, and crowded with small granules and crystals of magnetite, together with little needles and skeleton crystals, often twinned, and these from their extinction-angles appear in many instances to be labradorite. There are also many small lath-shaped crystals of triclinic felspar often considerably corroded (Pl. XIX. fig. 2). One or two of the skeleton crystals are shown in fig. 7, magnified 75 diameters. Fig. 6 in Pl. XIX. represents what appears to be a diminutive pseudomorph of magnetite after olivine, magnified 140 diameters. Taking the boundaries of the crystal-section as the brachydome (021) and the brachypinacoid (010), the angle for the faces 021 : $0\bar{2}1$ approximates to 80°. Minute pale greenish grains are also present which may consist of a dusty admixture of chlorite with some other mineral.

The devitrified glass in the thinnest parts of the section appears nearly colourless; where thicker it is of a pale brown tint.

The vesicles in this rock are exceedingly numerous and very irregular in form (Pl. XIX. fig. 1). They are filled with quartz, a chlorite-like mineral (apparently delessite in part), calcite, and sometimes chalcedony and a substance resembling felsitic matter. The larger grains in these microcrystalline aggregates usually show a positive uniaxial interference-figure, but occasionally the emergence of a negative bisectrix may be noted in convergent light, indicating that a biaxial mineral (probably felspar) is also present.

Quartz, chalcedony, or felsitic matter frequently borders the vesicles, the interior being filled with calcite only, with quartz only or with chlorite (delessite?) only, but often with an admixture of chlorite or delessite and quartz. The skeleton crystals are mostly of the H-shaped or swallow-tailed types. They very commonly show straight extinction, but in many cases the direction of maximum extinction makes angles with the axis of elongation varying from 12° to over 15°.

The rock appears to be closely allied to certain Bohemian melaphyres described by Bořicky *. It doubtless represents the once vitreous, superficial portion of an old lava-flow of basalt or andesite, and is probably one of the most ancient examples of such a rock with which we are yet acquainted.

No. XIV. S.W. side of Caer Caradoc, at the top of the hill. (Melaphyre Tuff.)—The fragments composing this tuff consist of a rock similar to that just described. They are mostly small, ranging from three or four millimetres in diameter to very minute dimensions. The sections of the fragments frequently show concavities on

* 'Petrographische Studien an den Melaphyrgesteinen Böhmens,' Archiv für Naturw. Landesdurchforsch. v. Böhmen, Bd. iii. Geol. Abth., Prag (1876).

their boundaries, such as are invariably seen on the surfaces of the fragments of tuffs formed from vesicular or scoriaceous lavas. (Pl. XIX. fig. 4.)

The general aspect of the hand-specimen is that of a dark iron-grey or bluish-grey rock, compact in texture, but appearing slightly vesicular when examined under a pocket-lens. It also shows some irregular spots of yellowish-white to pinkish-white crystalline matter, which effervesces briskly when touched with a drop of acid.

In thin section, under the microscope, the fragments composing the rock are seen to vary considerably in translucency, the groundmass in some being a more or less completely devitrified pale-brown glass, containing opaque matter which appears merely as fine dust under a magnifying power of 250 linear. In other fragments the opaque particles in the groundmass are larger, and the rock of which these fragments consist seems to differ in no appreciable respect from the melaphyre previously described which occurs in the immediate vicinity of this tuff.

In many of these fragments the magnetite grains are seen to be more closely massed along the margins of the fragments, giving rise to a narrow and perfectly-opaque black border, while in some instances the entire groundmass of the fragment has been rendered absolutely opaque through development of magnetite.

It has already been shown that a basic, vitreous lava, such as the basalt-glass of Kilauea, when heated for 260 hours at a temperature ranging from 700° to 1200° C., becomes strongly magnetic and absolutely opaque through separation of magnetite *. Bearing this fact in mind it may, I think, be inferred that the fragments constituting the melaphyre tuff of Caer Caradoc have not resulted from the mere crushing of a lava, but that they were ejected from a crater as lapilli and volcanic sand; that their surfaces, in many instances, were sufficiently heated to give rise to the formation of an opaque superficial crust of magnetite, while, in other cases, a more protracted roasting carried this process to its extreme limit, so that all the iron present in the lava in the protoxide state became converted into the magnetic oxide.

The action exerted upon a magnetic needle, when a specimen of the melaphyre lava (No. XII.) is brought near it, is exceedingly slight compared with that produced by a considerably smaller specimen of the melaphyre tuff (No. XIV.). Fig. 4 in Pl. XIX. represents part of a section of this tuff, magnified 18 diameters. The fragments and portions of fragments here shown exhibit a perfectly opaque groundmass, while the small felspar-crystals and skeletons lying in this groundmass appear unaltered and remain perfectly translucent. The broad light band passing diagonally across fig. 4 represents cementing material which, in this rock, consists of chalcedony. Irregularly shaped cavities occur in this cement, and these have been filled partly with pale green serpen-

* 'Notes on Alteration induced by Heat in certain Vitreous Rocks,' Proc. Royal Soc. vol. xl. (1886) p. 437.

tinous matter, probably derived from the decomposition of the pyroxenic constituents of the melaphyre fragments, and partly with calcite. Judging from the texture of this tuff, it is probable that the vent from which the lapilli were ejected was not very far distant.

No. VIII. S.W. side of Caradoc, about 80 feet below the Camp. (Amygdaloidal Melaphyre.)—A dark grey rock with small vesicles, some of which are filled with white and others with dark-green matter.

Under the microscope it is seen to consist of small lath-shaped crystals of triclinic felspar, usually corroded and occasionally bent, together with magnetite (sometimes in octahedra, but mostly in irregular grains), and a considerable amount of green matter, which appears in some cases to be chlorite, but is not improbably a palagonitic substance resulting from the alteration of interstitial glass. The felspar-crystals lie irregularly in all directions.

The vesicles are very irregular in form and some are filled with chlorite or delessite (the optical sign in the direction of the fibres is positive). Others are filled with calcite or quartz, while, at times, a little chalcedony is present. The section is stained in places by ferric oxide.

No. X. S.W. side of Caradoc, about 100 feet below the Camp. (Amygdaloidal Melaphyre.)—A compact dark brownish-grey rock with very small vesicles, some containing quartz, others a dark green substance. Under the microscope it appears, when examined with a low power, to consist of a felted mass of very minute felspar crystals with opaque interstitial matter. The rock, in fact, shows the "pilotaxitic" structure of Rosenbusch, unless, indeed, the black interstitial matter represents a once glassy groundmass now rendered opaque by separation of magnetite, in which case the structure would once have been "hyalopilitic." The vesicles contain chlorite and quartz, and are very irregular in form. The section is traversed by some delicate fissures now filled with quartz.

Fig. 3 in Pl. XIX. represents portion of a section of this rock.

No. VII. S.E. side of Caradoc, low down, perhaps 150 or 200 feet below the Camp. (Melaphyre.)—A rather pale greenish-grey to brownish-grey, finely-crystalline rock, presenting no striking peculiarities to the unassisted eye. Under the microscope it is seen to be more coarsely crystalline than any of the preceding.

The felspars, which constitute a large proportion of the rock, lie in all directions and, from their extinction-angles, appear to be labradorite, but in many cases they are partly converted into kaolin. Much brownish or greenish matter is present, often filling vesicles, in which case it usually forms divergent fibrous growths and minute spherulitic aggregates which have a positive optical sign. The section also shows rusty-brown patches of limonite, minute specks of pyrites and apparently a little unaltered magnetite. The felspars are often corroded and sometimes bent.

No. XV. Little Caradoc, N.W. side, about 100 feet above the

road to Comley. (Dolerite.)—A greenish-grey holocrystalline rock of rather coarse texture, mainly consisting of dark-green augite and greyish felspar.

Under the microscope the rock is seen to consist of crystals of perfectly unaltered augite, labradorite often partly converted into kaolin, magnetite, and interstitial patches of chlorite. The augite crystals, as a rule, appear to range from more than three millimetres to about one millimetre in length. The crystals of labradorite are frequently of somewhat larger dimensions.

## III. Conclusions with regard to the Melaphyres.

The foregoing descriptions show that, within a very limited area, the melaphyres of Caradoc differ considerably in texture and in structure. Some have once been basalt-glass or andesite-glass, such being the superficial portions of a lava-stream; others have possessed a certain amount of interstitial glass which has subsequently been rendered more or less opaque by the development of magnetite, while, at times, it appears to have been converted into a substance possibly allied to palagonite.

In some of these rocks the crystalline texture is very fine (pilotaxitic), while in the case of the dolerite from Little Caradoc it is comparatively coarse. Furthermore, near the summit of Caradoc we have a basalt-tuff or andesite-tuff.

These rocks are spoken of as altered basalt or andesite, since any pyroxene or olivine which they may once have contained is in most cases so completely replaced by alteration-products that it is impossible to define their original mineral constitution with precision. This is also partly due to the allotriomorphous character of those minerals which have undergone decomposition. The felspars and magnetite are, as a rule, the only original constituents which remain unaltered, and these at times have suffered very considerable change.

The term melaphyre, as indicating an altered basalt or andesite, seems perfectly applicable to these old lavas.

The dolerite of Little Caradoc differs from these rocks, in that the augite remains perfectly fresh, or is only altered along minute fissures, and the felspars are more or less turbid and altered, while in the lavas of Caradoc proper it is the pyroxenic constituent which has undergone decomposition, but the felspars remain fresh and, as a rule, unchanged.

Whether the dolerite of Little Caradoc may be regarded as a volcanic neck or plug, from which the basic lavas lying to the south-west of it emanated, is a point which field-work can alone demonstrate or disprove, but, taking into consideration the gradations of texture which these rocks present at different levels, such a supposition comes within the range of possibility.

## IV. The Felsitic Series.

The Felsitic Series in the Caradoc area is a very important one, but extremely difficult to work out under the microscope, since the structures characteristic of rhyolites are, in most cases, obscure, so obscure, in fact, that, unless exceptionally thin sections are examined, they may often completely baffle detection. After careful examination, however, it has been possible to recognize not only spherulitic structure and occasionally bands of spherulites, but also perlitic structure. The latter is very obscure in the best examples, but is sufficiently marked to prove that the structure is present.

It may be fairly well seen in a section made from a specimen collected a little above Caradoc Coppice, near the southern end of the hill and on its north-western flank. Very faint indications of the structure were first seen in this and in one or two sections from other spots in the neighbourhood. The sections were then reduced in thickness, and, in the thinnest portions of them, perlitic structure was found to be unquestionably present although still obscure. In ordinary transmitted light it is less easy to detect than between crossed nicols, and in the latter case it is rendered more apparent by a rapid rotation either of the section or, if a Dick microscope be used, of the nicols. The reason of this appears to be that the crystalline grains which lie in or along the perlitic fissures are, as a rule, slightly larger than those which constitute the main mass of the rock and that, although the optical orientation of the different grains along any one perlitic fissure is very diverse, yet on rapid rotation either of the section or of the crossed nicols the maximum illumination of one grain in the series is so quickly followed by the maximum illumination of each succeeding grain that the retina retains these impressions sufficiently long to receive the general impression of a narrow ring or of a number of narrow rings more brilliantly illuminated than the remainder of the section. Without having recourse to rotation these rings can, however, still be seen (Pl. XIX. fig. 5).

Spherulites are somewhat plentiful in these rhyolitic rocks. They are usually small, but not difficult to detect even under low powers. For the most part they are irregularly distributed, but in some of the sections examined they are more closely massed and occasionally coalesce in irregular bands.

Setting aside the devitrification which these rocks have experienced, we have their exact counterparts in many spherulitic obsidians of comparatively recent date, notably in those of the Yellowstone District, especially in some which occur near the Madison River.

Ordinary fluxion-banding appears to be very poorly represented in the Caradoc rhyolites. Evidence of such structure has been better seen on the ground than under the microscope. On the S.E. flank of Caradoc, a little to the south of the Camp and about half way up the hill, there is, for instance, an outcrop of felsite, on the weathered surface of which there is a well-marked banding visible. At this

point the strike is S. 80° W. and the dip about 55° towards the north. A microscopic section of this rock, however, shows scarcely any traces of fluxion-banding.

Irregularly-shaped vesicles, filled with quartz &c., are often present in these rhyolites, and they occasionally show a tendency towards elongation in a definite direction. This is well seen in some of the exposures of rhyolite occurring at the top of Caradoc close to and within the Camp; but the forms of these vesicles, when viewed under the microscope, are often remarkably irregular, throwing out processes in all directions, the latter frequently constricted to mere threads near their points of origin from the main vesicle, then expanding and finally tapering to sharp points. In spite of this irregularity, however, they may be seen to have a rudely linear arrangement in the rock. Fluxion structure, as evidenced by streams of microliths, is not to be detected in rocks which have undergone such complete devitrification, save perhaps in hazy banding, produced by slight differences in crystalline texture.

For the purpose of ascertaining how far certain structures in vitreous rocks may be destroyed or rendered invisible through subsequent alteration, I have examined a number of sections of unaltered obsidians and pitchstones in search of perlitic and fluxion structures, so delicate that devitrification would almost infallibly obliterate them or render them so indistinct that they could no longer be recognized with any certainty. The following are a few notes on the subject, which may possibly be of some interest:—

1. In a perlitic obsidian (from Schemnitz, Hungary) the breadth of the perlitic fissures ranges from about $\frac{1}{9600}$ to $\frac{1}{2400}$ of an inch. Such a continuous perlitic fissure, when seen in section, may often be observed to thin away from the larger dimension to nothing. One can easily imagine that the devitrification of such a rock would result in the total obliteration of the more delicate fissures.

The fluxion-banding in this section consists of streams of microliths. A portion of one of the broadest lines in one of these streams measures $\frac{1}{1200}$ of an inch. Devitrification might not obliterate such a band, but it might easily render the recognition of its component microliths impossible.

2. In a section of a Mexican obsidian no fluxion-banding whatever is visible under the microscope, the only indication of flow consisting in the uniform direction of elongation of included gas-pores. The numerous microliths present in the section lie with their longest axes in all directions.

There are, therefore, in such a rock no structures which would bear testimony to its origin after devitrification. The result of such change would be simply a felsite without fluxion-banding and without perlitic structure.

In cases such as these, mode of occurrence and associations in the field could alone give a clue to the original nature of the rock.

The best example of fluxion structure which I have yet met with in the Caradoc district is in a rhyolite-tuff occurring at Bowdler's Chair at the southern extremity of the Gaerstones ridge. The

specimen collected, which is merely a small surface-chip, is a brown to dark purplish-grey rock, showing a brecciated appearance when examined with a pocket-lens.

The section has been taken at a depth of about an inch from the weathered surface and shows, under the microscope, that the rock is in great part composed of fragments of rhyolite (devitrified obsidian) which exhibit a delicate, well-defined fluxion-banding. This banding is frequently sinuous, but some of the fragments show markings which approximate to damascene structure.

The fragments are completely devitrified, displaying a micro- to crypto-crystalline structure when viewed between crossed nicols. There can, I think, be no doubt that they are fragments of devitrified obsidian.

With regard to the material in which they are embedded a more guarded opinion should be given. It is somewhat darker in colour than the rhyolite fragments and contains numerous little crystals and fragments of crystals of felspar, some of which show the repeated twin-lamellation of plagioclase and, in one good example, the extinction-angle clearly indicates labradorite. Occasionally small grains of quartz may also be detected on employing convergent light. A little magnetite is likewise present.

This matrix, in which the larger rhyolite-fragments lie, also contains much smaller rhyolitic fragments, practically mere dust. The section is traversed by a network of very delicate fissures, which are filled with quartz and which cut through the rhyolitic fragments and the substance in which they are embedded.

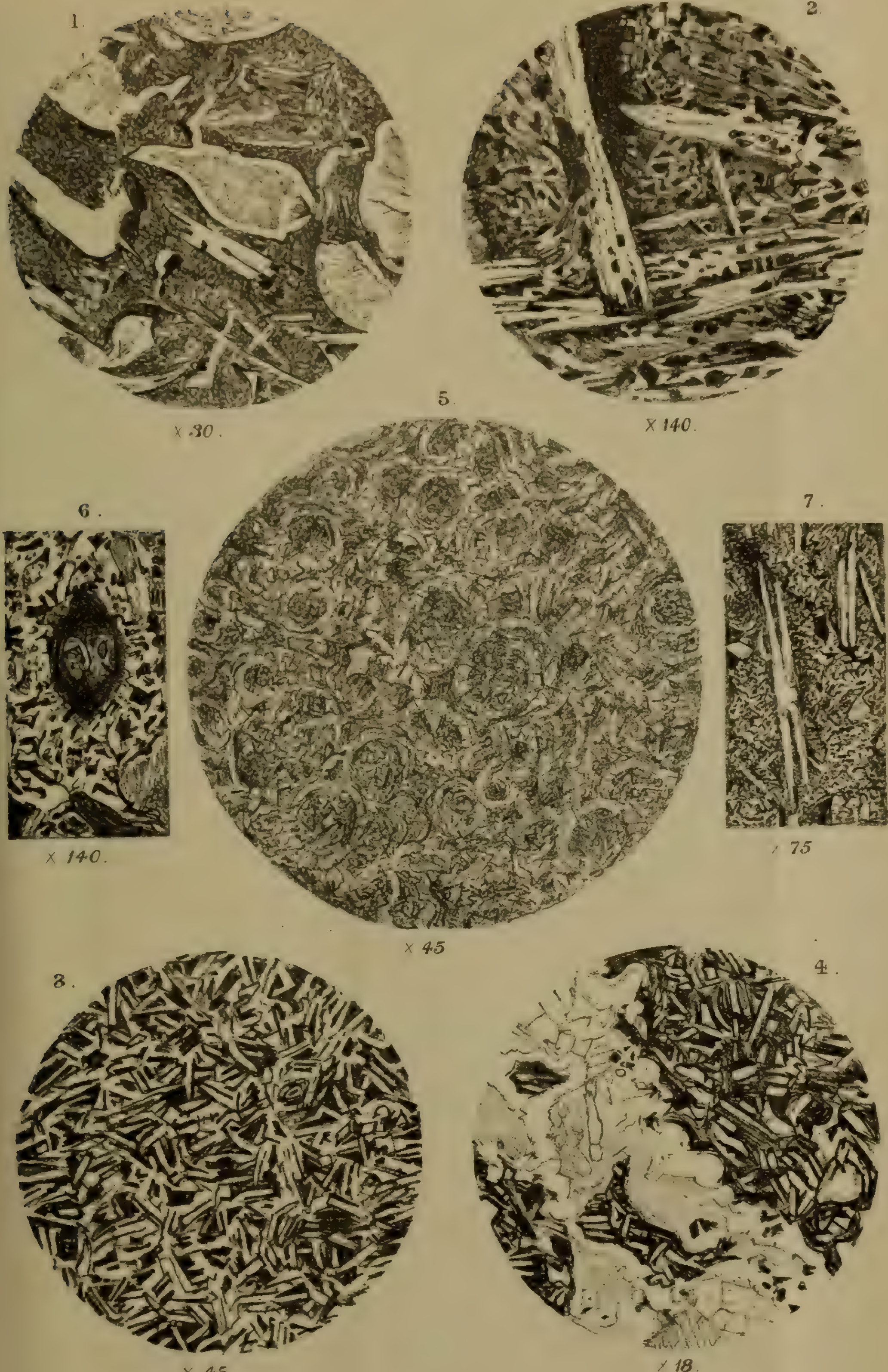
## V. Conclusions with regard to the Felsites.

Looking at all the evidence afforded by the felsites described in this paper and by others collected at the same time but showing less marked characters, it seems that we have, in the Caradoc area, a great thickness of rhyolites, probably associated with tuffs, which, if of fine texture, might easily escape recognition in the field or afford no clear proof of their origin even under the microscope. The rock of Bowdler's Chair appears, in part at least, to be an unquestionable rhyolite-tuff, and as the adjacent felsites seem closely to resemble those of Caradoc, it may, I think, be assumed that the Caradoc and Hope Bowdler masses form part and parcel of one great series of lavas and tuffs, which, judging from their thickness, must once have been continuous over a wide area.

Before attempting to examine these rocks, I was aware that Prof. Blake * and Dr. Callaway † had alluded to the presence of rhyolites among them, but since their writings contained no detailed description which afforded evidence that these rocks were true rhyolites, further investigation seemed desirable. In the

* 'On the Monian and Basal Cambrian Rocks of Shropshire,' Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 386.

† 'On the Unconformities between the Rock Systems underlying the Cambrian Quartzite in Shropshire,' p. 120 of this volume.




Frank Rutley del. F. H. Michael lith. Mintern Bros. imp.

1, 2, 3, 4, 6, 7. MELAPHYRES OF CARADOC HILL.
5 PERLITIC FELSITE ABOVE CARADOC COPPICE.

foregoing paper I have, therefore, endeavoured to supply some of the proof which seemed, hitherto, to be wanting.

## VI. Supplementary Note.

When this paper was read I was not aware that Prof. Lapworth had been devoting his attention to the eruptive rocks of Caradoc and its neighbourhood. In the discussion which followed, Sir Archibald Geikie alluded to the detailed map which Prof. Lapworth had constructed and of the existence of which I was unfortunately ignorant.

On writing to Prof. Lapworth he most generously gave me a large amount of valuable information relating to his work and forwarded his unpublished map to me for inspection. The latter is, unquestionably, a very careful and detailed piece of surveying: a map which, when published, will be the most important exponent of the geology of this district which has ever appeared. On it the basic rocks and rhyolites are duly recognized, while the boundaries of many intrusive sheets which, in my brief examination of the ground, passed unnoticed by me, are laid down.

It is only just that I should take this opportunity of bearing testimony to the splendid work which Prof. Lapworth has done, and is doing, in this district, and I would also gratefully acknowledge his courtesy in so readily communicating the result of his labours.

## EXPLANATION OF PLATE XIX.

Fig. 1. Vesicular melaphyre (altered vesicular basalt-glass). S.W. side of Caer Caradoc, near the top of the hill. × 30 linear.
2. Ditto, × 140, showing corroded felspars.
3. Melaphyre (amygdaloidal), showing pilotaxitic structure. S.W. side of Caradoc, about 100 feet below the Camp. × 45.
4. Melaphyre tuff (altered vesicular basalt-glass tuff). S.W. side of Caer Caradoc, at the top of the hill. The broad, pale, diagonal band represents cementing material. × 18.
5. Perlitic felsite (devitrified obsidian). Above Caradoc Coppice, S. end of Caradoc Hill, N.W. flank. × 45. Crossed nicols.
6. Portion of the section represented in figs. 1 and 2, showing a pseudomorph of magnetite after olivine. × 140.
7. Portion of the section represented in figs. 1, 2, and 6, showing skeleton crystals. × 75.

Figs. 1, 2, 6, and 7 are from specimen No. XII.
Fig. 3 is from specimen No. X.
Fig. 4 „ „ „ No. XIV.
Fig. 5 „ „ „ No. 11.

## Discussion.

The President alluded to the detailed mapping of the Caradoc region by Prof. Lapworth, which, though not yet published, was known to many Fellows of the Society, and included the recognition of rhyolites, rhyolitic tuffs, and basic sheets. He believed that the views of Prof. Lapworth and Mr. Rutley would be found to be in the main accordant.

Prof. Bonney also spoke.

The Author, in reply, stated that he had not seen the large-scale map of Caradoc, mentioned by the President, nor was he aware that Prof. Lapworth had mapped these volcanic rocks. He trusted, however, that, in both instances, the results would be found to correspond.

He fully endorsed Prof. Bonney's remarks with reference to the difficulties met with in attempting to work out the original structures in the felsites.

30. *On a* Section *of the* Rhætic Rocks *at* Pylle Hill (Totterdown), Bristol. By Edw. Wilson, Esq., F.G.S., Curator of the Bristol Museum. (Read May 6, 1891.)

Although the Rhætic rocks have a wide horizontal distribution in the neighbourhood of Bristol, it is but seldom that they are exposed at the surface. In the absence of natural inland sections, and of quarries on the horizon of a thin series of rocks which yield no minerals of commercial value, we have generally to trust to new railway-cuttings or other artificial excavations for affording us opportunities for their examination. The construction of the Bristol Relief Railway has, in this way, recently given us an excellent section of these rocks.

In the deep cutting of this railway at Pylle Hill, Totterdown, on the south side of the city of Bristol, we get the following interesting rock-sequence. From the level of the line to a height of about forty feet above it, the red and green marls of the Upper Keuper are exposed. These variegated marls terminate upwards in nine feet of light greenish-grey marls—the "Tea-green Marls" of Etheridge. Above the Keuper Marls come the Rhætic Beds, comprising two well-marked subdivisions, namely the black "paper shales" of the *Avicula-contorta* series below, and the light grey limestones and laminated shales of the Upper Rhætic series above, the two series taken together being only seventeen feet in thickness. The Rhætic Beds are succeeded by three or four feet of rubbly, cream-coloured limestones and shales, usually termed "White Lias," and the section is completed by some nine or ten feet of the regularly bedded limestones and shales of the Lower Lias, containing fossils characteristic of the zone of *Ammonites planorbis*.

The railway runs E. and W., or approximately along the strike of the beds—the dip being S.S.E., at an average angle of from 3° to 4°. In the line of section the beds are nearly horizontal, but with a very gentle synclinal arrangement *.

This is not the first time the Pylle Hill section has been described. In the year 1860 the late Charles Moore read a paper before this Society "On the so-called Wealden beds at Linksfield, and the Reptiliferous Sandstones of Elgin," an abstract of which, published in the Quarterly Journal for that year †, gives a section at "Pylle Hill on the Bristol and Exeter Railway," and therefore at a very short distance from the section now under consideration.

The section given by Moore is, however, so incomplete, and the

* Owing to the form of the ground—the railway cutting through a hillside with a steep slope to the north—and to the southerly dip of the beds, the Lower Lias and Upper Rhætic beds here referred to are shown in the southern, but not in the northern side of the cutting, and the horizontal section, which is taken along the centre line of the railway, also shows considerably less of the upper beds than the vertical section, which is constructed from measurements made on the south side.

† Quart. Journ. Geol. Soc. vol. xvi. p. 445.

information relating to it so meagre—probably because the railway-cutting when examined was already in great measure defaced—that it is practically valueless. A re-description of the Pylle-Hill section therefore appears desirable whilst it is in a fresh state. In a very short time, indeed, the new cutting, which, like the old one, is sloped at so high an angle as to be almost inaccessible, will become obscured by rainwash and vegetation, and thus be no longer available for detailed examination.

The first thing that strikes one in the Pylle-Hill section is the very limited development of the Rhætic Beds, the whole series, according to my estimate, measuring only seventeen feet, or not more than half the thickness which they usually attain in the West of England *. At Westbury-on-Severn, for instance, the Rhætic Beds are 33 feet thick, at Aust Cliff 34 feet, and at Penarth 42 feet.

There can scarcely be any doubt as to which is the true base of the Rhætic at Pylle Hill, but it is possible there may be some difference of opinion regarding its upper limit. The precise point where the line should be drawn between the Lias and the Rhætic in the West of England is still a matter of some uncertainty, our chief Rhætic authorities, Moore, Wright, Etheridge, Tawney, Dawkins, and H. B. Woodward, having taken very different views on this question. At the base of the Lower Lias we generally find a variable series of light grey to cream-coloured limestones and shales, which are commonly called "White Lias." This quarry-man's term for these beds is, however, an unfortunate one, for since it was first adopted by William Smith, in the year 1815, it has been applied by different authors to very different things—some at any rate of the rocks which it covers being certainly Rhætic, whilst others are as certainly Lias. In the Pylle-Hill section, I take the three or four feet of light-coloured rubbly limestones and finely laminated shales *o*, *p*, *q*, *r*, to represent the so-called "White Lias." The fossils of these beds are bivalve molluscs mostly in the condition of indeterminable casts, but we can make out with certainty *Modiola minima*, *Monotis decussata*, a *Lima* (apparently *Lima gigantea*), and a *Pleuromya*. The presence of these shells, and the absence of characteristic Rhætic forms, induces me to class these beds with the Lias rather than with the Rhætic. I take the bed *n* of my section, which is evidently the equivalent of the "Cotham Marble" or "Landscape-stone," as the highest distinctive Rhætic rock in this section. Probably some authors would include in the "White Lias" not only the beds *o* to *r*, but also the underlying light grey shales and limestones weathering white, from *i* to *n*. Whatever we choose to call them, these latter rocks are certainly Rhætic, the bed *i*, for instance, containing such characteristic Rhætic fossils as *Cardium rhæticum*, *Pecten valoniensis*, *Schizodus Ewaldi*,

* Fourteen years ago the Rhætic Beds were penetrated in an excavation for the foundations of the Bristol Waterworks Pumping Station, Oakfield Road, Clifton, on the north side of the city, and were there shown by the late Mr. E. B. Tawney, F.G.S., to be only sixteen feet in thickness. Proc. Bristol Nat. Soc. n. s. vol. ii. (1878) p. 179.

Q

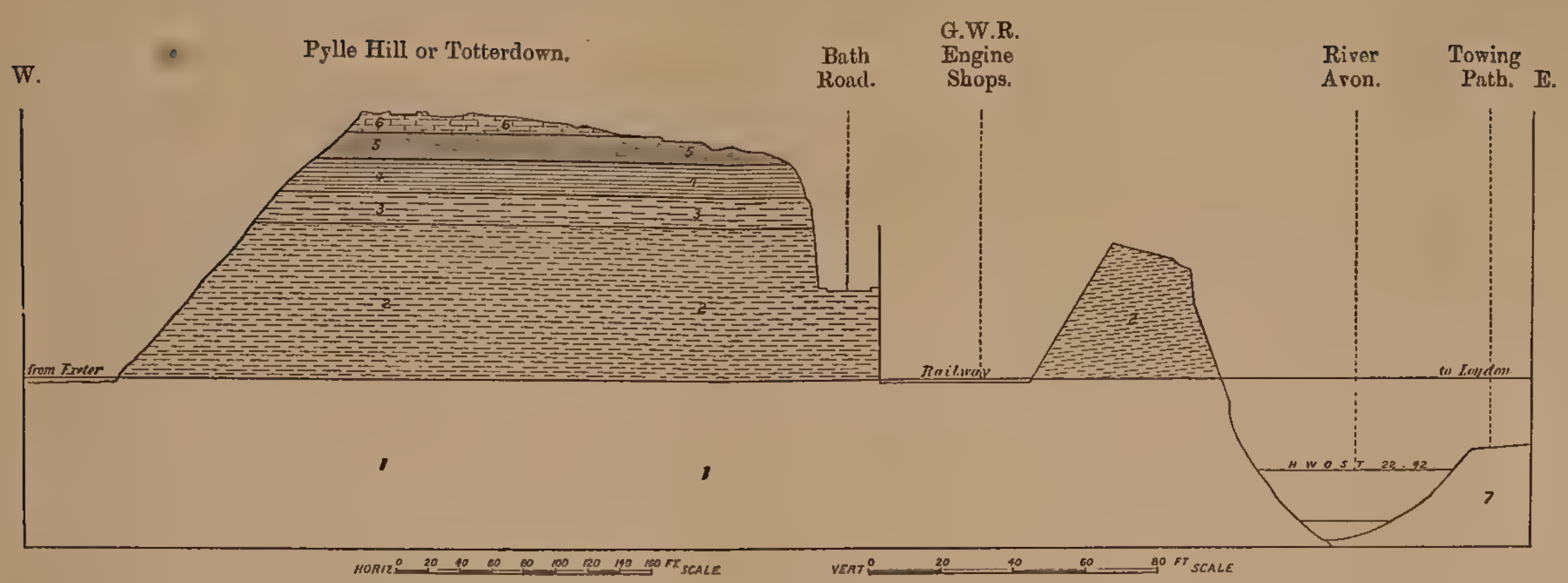
*own, Bristol.*

| ft. | in. | |
|---|---|---|
| 2 | 0 | *Am.* (*Ægoceras*) *planorbis*, *Am.* (*Ægoceras*) *torus*, D'Orb.=*Johnstoni*, Sow. |
| 4 | 5 | *Lima gigantea*, *Pholadomya glabra*, etc. |
| 1 | 0 | *Ostrea liassica.* |
| 1 | 9 | *Lima gigantea* (?). |
| 0 | 6 | |
| 0 | 9 | *Modiola minima*, *Monotis decussata*, *Lima gigantea* (?), *Pleuromya* sp. |
| 0 | 9 | *Monotis decussata.* |
| 0 | 3 | Small turbinate gasteropods (indeterminable). |
| 1 | 11 | Ostracoda, of small size, similar to those in bed *i*. |
| 0 | 7 | *Estheria minuta*, var. *Brodieana*, and a few small ostracoda. *Naiadita.* |
| 0 | 10 | |

W

Towing Path. E.

*Section of the Rhætic rocks at Pylle Hill (Totterdown), Bristol.*




| | | ft. | in. |
|---|---|---|---|
| 7. | Alluvium. | | |
| 6. | Lower Lias limestones and shales | 11 | 2* |
| 5. | Upper Rhætic shales and limestones | 7 | 7 |
| 4. | Lower Rhætic, *Avicula-contorta* shales | 9 | 5 |
| 3. | Upper Keuper "Tea-green Marls" | 9 | 0 |
| 2. | Upper Keuper red and green marls, above railway-level. | | |
| 1. | do. do. below do. | 40 | 0 |
| | | 77 | 2 |

*Note.*—"Totterdown" ("Totter Down" on the Ordnance Survey One-inch-to-a-mile Map) is the name now used for a suburb of Bristol in which Pylle Hill or Totterdown is situated.

The vertical scale is exaggerated in the above section, being about twice the horizontal.

* 11′ 2″ of these beds are not shown in the Diagram-section, for the reasons stated in the footnote on p. 545.

*Section at Pylle Hill or Totterdown, Bristol.*

| | | ft. | in. | |
|---|---|---|---|---|
| Lower Lias Limestones and Shales. | *v.* Soil with limestone rubble | 2 | 0 | *Am.* (*Ægoceras*) *planorbis*, *Am.* (*Ægoceras*) *torus*, D'Orb.=*Johnstoni*, Sow. |
| | *t.* Limestones and shales, regularly bedded in alternating seams of from 2″ to 6″ | 4 | 5 | *Lima gigantea*, *Pholadomya glabra*, etc. |
| | *s.* Limestones, regularly bedded in seams of from 2″ to 4″ with laminated shaly partings | 1 | 0 | *Ostrea liassica.* |
| | *r.* Limestone, light coloured, argillaceous, rubbly | 1 | 9 | *Lima gigantea* (?). |
| | *q.* Limestone, do. do. | 0 | 6 | |
| | *p.* Limestone, do. , with bivalve shells, chiefly as casts | 0 | 9 | *Modiola minima*, *Monotis decussata*, *Lima gigantea* (?), *Pleuromya* sp. |
| | *o.* Shales, brown, arenaceous, finely laminated, with small crushed bivalves | 0 | 9 | *Monotis decussata.* |
| Upper Rhætic Series. | *n.* Limestone, compact, light blue, concretionary, with conchoidal fracture and dendritic markings, 'Cotham Marble' 2″ to 8″, average thickness | 0 | 3 | Small turbinate gasteropods (indeterminable). |
| | *m.* Shales, light blue, finely laminated, with thin sandy seams, and two thin bands of compact white limestone in the middle portion of the series | 4 | 11 | Ostracoda, of small size, similar to those in bed *i*. |
| | *l.* Limestone, regularly bedded, light blue, weathering to a pale greenish-yellow tinge, laminated and jointed, 6″ to... | 0 | 7 | *Estheria minuta*, var. *Brodieana*, and a few small ostracoda. *Naiadita.* |
| | *k.* Shales, thinly laminated, light grey, weathering to a pale greenish-yellow tinge, with thin seams of compact argillaceous limestone | 0 | 10 | |
| | *i.* Limestone, argillaceous, light blue, weathering to a pale greenish-yellow tinge; a massive bed, but regularly laminated and closely jointed, with numerous small plants and valves of ostracoda. Also bivalve shells and fish-scales and teeth | 1 | 0 | *Actæonina* sp., *Schizodus Ewaldi*, *Cardium rhæticum*, *Cardium* sp., *Plicatula intusstriata*, *Pecten valoniensis*, *Acrodus minimus*, *Saurichthys acuminatus*, *Gyrolepis Albertii*, *Naiadita*, ostracoda. |
| *Avicula-contorta* Shales. | *h.* Shales, black, earthy, imperfectly laminated above, with shell-fragments, coprolites, and fish-scales; more regularly laminated below, with bivalve shells retaining the test | 0 | 10 | *Avicula contorta*, *Schizodus Ewaldi*, *Myacites striato-granulata*, *Cardium rhæticum*, *Pecten valoniensis*, *Ostrea alpina* (?), *Gyrolepis Albertii.* |
| | *g.* Limestone, compact, blue, shelly, in one or two seams, iron-stained on surfaces, and rotting away into a soft sandy clay in the middle, along joint-planes | 0 | 3 | *Pecten valoniensis*, *Avicula contorta*, *Plicatula Archiaci*, *Schizodus Ewaldi*, *Modiola minima*, *Natica Oppelii*, *Actæonina* (*C.*) *oviformis*, sp. & sp. "*Chemnitzia*," *Turritella* (?), *Schizodus concentricus*, *Lucina Stoppaniana*, *Serpula constrictor.* |
| | *f.* Shales, black, alternately more regularly laminated and more earthy, with occasional pyritic seams, very fossiliferous at various levels, the *Ophiolepis* at 13″ and 20″ below *g* | 2 | 10 | *Avicula contorta*, *Schizodus Ewaldi*, *Ostrea* (*A.*) *alpina*, *Cardium* sp., *Myophoria Emmrichi*, *Gervillia præcursor*, *Ophiolepis Damesii*, *Acrodus minimus*, *Gyrolepis Albertii*, *Myacites striato-granulata*, *Anatina Suessi.* |
| | *e.* Shales, black, earthy, pyritic, passing down into | 0 | 3 | |
| | *d.* Shales, black, rather thickly laminated, clayey, with thin sandy seams, containing bivalves with well-preserved tests, a few scattered coprolites and small reptilian bones | 2 | 0 | *Schizodus Ewaldi*, *Myophoria Emmrichi*, *Avicula contorta*, *Ostrea alpina.* |
| | *c.* Pyritic Sandstone, laminated, thin but continuous, ⅛″ to 2″ | 0 | 1 | |
| | *b.* Shales, black, thickly laminated with thin sandy streaks, passing down into | 1 | 3 | *Pleurophorus angulatus*, *Ostrea alpina*, *Cardium rhæticum*, *Avicula contorta*, *Pecten valoniensis*, *Gervillia præcursor.* |
| | *a′.* Shales, black, firm, and regularly laminated, iron-stained along joints, generally unfossiliferous, but with scattered coprolites, and scales of *Gyrolepis*, and near the top the shells of bed *b*, passing down into | 1 | 6 | Coprolites, scales of *Gyrolepis*, and a few bivalves at the top. |
| | *a.* Shales, black, earthy, non-laminated; at the base a very thin seam and small pockets of pyritic grit, containing fish-teeth, scales and fin-spines, coprolites, and white quartz-pebbles | 0 | 5 | *Acrodus minimus*, *Hybodus minor*, *Gyrolepis Albertii*, *Hybodus cloacinus*, *Saurichthys acuminatus*, *Ceratodus* sp. |
| Upper Keuper. | "Tea-green Marls," light greenish-grey marls, more arenaceous towards the top, with the carbonized remains of plants embedded in a vertical position, graduating down into | 9 | 0 | Plant-remains (indeterminable). |
| | Red Marls, with bands of greenish-grey marl and sandstone at wide intervals, exposed down to the railway-level about | 40 | 0 | |
| | | 77 | 2 | |

*Acrodus minimus*, *Saurichthys acuminatus*, and *Gyrolepis Albertii*. I consider the limestones and shales *i* to *n* homotaxial with the shales and nodular limestones containing *Estheriæ* which we find in the Midland district directly overlying the *Avicula-contorta* shales. These beds I designate "Upper Rhætic," a term which seems preferable to that of "White Lias" as applied to rocks which, in a geological sense, are not Lias at all.

Another feature which the Pylle-Hill section displays very clearly is the intimate connexion between the "Tea-green Marls" and the underlying Red Marls of the Upper Keuper. Whilst there is a sharp physical line of demarcation, as well as a total difference in mineral character, between the "Tea-green Marls" and the black shales of the *Avicula-contorta* series, the "Tea-green Marls" are themselves seen to blend insensibly into the underlying Red Marls of the Keuper. This section, therefore, like so many others at the same horizon, both in the West of England and in the Midland Counties, indicates that the "Tea-green Marls" belong to the Keuper and not to the Rhætic series, and also that they cannot properly be looked upon as passage-beds between those two formations. The authors who first determined Rhætic rocks in England —Mr. Charles Moore and Dr. Thomas Wright—took this view: and drew the dividing line between the Rhætic and the Trias at the base of the *Avicula-contorta* shales, classing the underlying greenish-grey marls with the Keuper *. In his original description of the section at Garden Cliff, Westbury-on-Severn, Mr. R. Etheridge placed the "Tea-green Marls" in the Rhætic series †, but in 1871 he had come to consider these beds as more properly associated with the Keuper ‡. The Geological-Survey authorities, although admitting the fact that the "Tea-green Marls" graduate down into the variegated marls of the Upper Keuper, have nevertheless been in the habit of classing these beds with the overlying black Paper Shales, and the "White Lias" under the common term "Penarth or Rhætic beds" §. Mr. H. B. Woodward advocates this method of classification, partly on the ground that on the maps of the Geological Survey it was found more practicable to draw the line between the Rhætic and the Keuper beds at the base of the grey marls, and partly because in certain Rhætic sections, such as those near Axmouth and Watchet, there are appearances of a transition, for "bands of very dark, if not black, marl alternate with pale grey and buff marls, above the Red Marls of the Keuper" ||. It is also alleged that the

* C. Moore, Quart. Journ. Geol. Soc. vol. xvii. (1861) p. 493; T. Wright, *ibid.* vol. xvi. (1860) pp. 378, 380, 383, and Pal. Soc. Monogr. 'Lias Ammonites' (1880), p. 165, fig. 13.

† 'On the Rhætic or *Avicula-contorta* beds at Garden Cliff, Westbury-upon-Severn,' Proc. Cottesw. Nat. Field Club, vol. iii. (1865) p. 218.

‡ 'On the Physical Structure and Organic Remains of the Penarth (Rhætic) Beds of Penarth and Lavernock, with a description of the Westbury-on-Severn Section,' Trans. Cardiff Nat. Soc. vol. iii. (1870–71) p. 39.

§ H. B. Woodward, Mem. Geol. Surv., 'Geol. of East Somerset and the Bristol Coal-Fields,' p. 69.

|| *Id.* 'Geology of England and Wales,' 2nd ed. (1887), pp. 243–246; and 'Notes on the Rhætic Beds and Lias of Glamorganshire,' Proc. Geol. Assoc. vol. x. (1888) p. 529.

"Tea-green Marls" and the Upper Rhætic shales possess very similar mineral characters. Whilst admitting the evidences of a transition between grey Keuper marls and the *Avicula-contorta* shales in the sections referred to by Mr. H. B. Woodward, I would point out that there is no evidence that the "Tea-green Marls" in the sections where there is no upward passage are the same "Tea-green Marls" as those in the sections where there is a passage. The "Tea-green Marls" vary in thickness very considerably in different places. When, moreover, we consider the vast difference in the development of the Upper Keuper rocks in the different districts where these sections occur, it seems impossible to suppose that the light grey marls into which the Red Marls so generally graduate upwards can be strictly homotaxial in all these sections. Except for a faint resemblance in colour, the mineral characters of the "Tea-green Marls" are totally different from those of the Upper Rhætic shales, and the organic remains found in them are also different. I adhere therefore to the view, which I have on a former occasion expressed, that, as a rule, both in the West of England and in the other parts of the country where these rocks occur, the "Tea-green Marls" ought to be classed with the Keuper, with which they are always stratigraphically so closely linked *.

Most of the more characteristic invertebrate fossils of the British Rhætic Beds are found at Pylle Hill, together with a few which are new to this country, and some of these possibly also to science.

Vertebrate remains are comparatively scarce. There is no true "Bone bed" as at Aust Cliff, but at the base of the *Avicula-contorta* shales there is a very thin and irregular seam of pyritic grit containing the teeth, scales, and coprolites of fishes. Bed *g*, a compact blue shelly limestone near the top of the Paper Shales, yields, in addition to the commoner Rhætic bivalves, a number of small gasteropods, mostly belonging to the genus *Actæonina*. The occurrence of the tiny brittle-star *Ophiolepis Damesii* in bed *f* is interesting, as it has not hitherto been recorded from the Bristol district.

In the Upper Rhætic series the thick bed of limestone *i* yields innumerable remains of the little freshwater plant *Naiadita*, described by the Rev. P. B. Brodie in his classic work on Fossil Insects †, and by the late Prof. J. Buckman, in the pages of the Quarterly Journal ‡, as having been derived from the "Lias" of Bristol. Associated with these plants are innumerable tests of minute ostracoda, which Prof. T. Rupert Jones tells me probably belong to two species of *Darwinula*. The succeeding bed of limestone *l* also contains scattered fragments of *Naiadita* associated with the well-known ostracod *Estheria minuta*, and minute ostracoda similar to those found in beds *i* and *l* crowd the surfaces of the laminæ of the overlying shales.

* 'The Rhætics of Nottinghamshire,' Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 451.

† 'Fossil Insects,' p. 92 *et seq.*

‡ 'On some Fossil Plants from the Lower Lias,' Quart. Journ. Geol. Soc. vol. vi. (1850) pp. 414–415, figs. 2, 3, 4; see also W. W. Stoddart, Proc. Bristol Nat. Soc. n. s. vol. ii. (1879) p. 280.

The occurrence of plant-remains in the "Tea-green Marls" is a matter of some interest; unfortunately the state of their preservation is too imperfect to admit of their affinities being determined with precision.

I am indebted to the Great Western Railway Company for permission to examine the railway-cutting at Pylle Hill, and to Mr. W. K. Lawrence, Engineer to the Bristol Relief Railway, for the section from which the diagram illustrating this communication has been constructed.

## Discussion.

Mr. Etheridge congratulated Mr. Wilson on the careful way in which he had worked out the new section of the Rhætic beds at Pylle Hill, near Bristol, which forms a continuation of the bed exposed nearly forty years ago. The Author had added several new species to the fauna of these shales and limestones, and discussed the question of the Tea-Green Shales, so named by the Geological Survey, and their relation to the Red Marls below and the Black Shales above. The vertical section prepared by the Author was mainly the same as those well known at Westbury, Penarth, and the exposures in Somersetshire and Gloucestershire long ago published by the Survey, and also others in Nottinghamshire and Leicestershire carefully worked out by the Author himself.

Mr. H. B. Woodward remarked that the Cotham Marble occurred at the base of the White Lias near Bath, and it was not clear that the bed marked as its equivalent in the Author's section was really on the same horizon. Several layers of similar texture occurred in the White Lias. However, he was prepared to believe in a certain amount of overlap of the White Lias by the Lower Lias in parts of Gloucestershire and Warwickshire. In the latter county the "Guinea-bed" appeared to be a *remanié* layer at the base of the Lower Lias, containing as it does Rhætic as well as Lower-Lias fossils. With regard to the Grey or Tea-Green Marls he admitted that it was mainly a matter of convenience that they were mapped by the Geological Survey with the Rhætic beds; in some localities they are more closely connected with the variegated Keuper Marls, but in other localities they are quite as intimately connected with the overlying Rhætic shales.

The Rev. H. Winwood alluded to the difficulties attending the examination of these beds, and the industry shown by the writer in working out their contents. Whatever might be the position of the Cotham Marble in this section (which must be admitted to be abnormal), in most, if not all, of the typical sections in the Bath district it invariably came in at the base of the White-Lias rubbly beds, and overlying the shales. He was glad to find corroborated Charles Moore's view that the White Lias belonged to the Rhætic formation.

Prof. T. Rupert Jones mentioned that the Rhætic ostracoda from Pylle Hill, which the Author had sent to him for examination, probably represented two species belonging to the genus *Darwinula*, of brackish-water habitat.

# 31. *The* Inferior Oolite *of the* Cotteswold Hills, *with* Special Reference *to its* Microscopical Structure. By Edward Wethered, Esq., F.G.S., F.C.S., F.R.M.S. (Read May 6, 1891.)

[Plate XX.]

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## Part I.—The General Structure.

### (a) *Introduction.*

The main divisions of the Inferior Oolite in the Cotteswold Hills are known to geologists who have made a study of Jurassic rocks, but to those who have not done so and to foreigners they may be less familiar. In order, therefore, that my remarks may be the more easily understood, I indicate the following main divisions which I propose to adopt, deferring my explanations of them till later on. They are given in descending order :—

Ragstones.
Upper Freestones.
Oolite Marl.
Lower Freestones.
Pea Grit.
Transition Beds, resting on the Upper Lias.

### (b) *The Transition Beds.*

*Position and General Structure.*—There has been considerable discussion among geologists as to where the line is to be drawn between the Inferior Oolite and the Upper Lias. To give even a summary of the controversy would take up considerable space and tend to divert the reader's attention from the primary object of this paper. I will, therefore, only mention the views of two geologists who may be said to represent the respective contentions. The late Dr. Wright, F.R.S., referring to the zone of *Harpoceras opalinum*, said *: "This zone was formerly grouped with the Cephalopoda-bed of Frocester; but, as it contains some species which are limited to

* 'Monograph of the Lias Ammonites,' Pal. Soc. vol. xxxiii. (1879) p. 148.

this horizon and are associates of *H. opalinum*, it is best to treat it as the highest zone of the Lias." Mr. Hudleston, F.R.S., takes a different view, and says *: "Turning now to the lower boundary, there seems to be a general opinion that the Sands of the Inferior Oolite should be restored to their old position as part of that series, which will, therefore, include the Cephalopoda-bed of the Cotteswolds and its Dorsetshire equivalents. As a matter of fact there are but few Gasteropoda in sufficiently good condition in these *essentially transition* beds between the Lias and the Oolites to make their acquisition of much value, and consequently but few specimens are likely to be selected for description from them." The italics are mine, and I have given the quotation because of the words "*essentially transition beds*," for I regard the beds commencing with the "Sands" and ranging up to what I shall call the "Pea-Grit Series" as transitional between the Inferior Oolite and Upper Lias. By the name of Transition Beds I shall refer to them in this paper.

For the most part the lowest beds of the Inferior Oolite and uppermost beds of the Lias are covered by talus. It is therefore not often that we have the advantage of seeing them; but, during the making of the Midland and South-Western Junction Railway between Andoversford (near Cheltenham) and Cirencester, a complete succession of the strata betwixt the Upper Lias and the Pea-Grit Series of the Inferior Oolite has been exposed. This section has been briefly described by Mr. S. S. Buckman in the Proceedings of the Cotteswold Naturalists' Field Club for 1889–90. It occurs in the third cutting east of Andoversford, and the following is a vertical section of the beds in ascending order:—

*Section of the Transition Beds E. of Andoversford, near Cheltenham.*

| | ft. | in. |
|---|---|---|
| 6. Argillaceous beds with Calcareous Nodules ................ | 10 | 0 |
| 5. Irregular bedded material, mostly argillaceous, with *Rhynchonella cynocephala* at the base ...................... | 12 | 0 |
| 4. Calcareous Bed ............................................. | | 10 |
| 3. Cephalopoda-bed ............................................ | 1 | 2 |
| 2. Crystalline Limestone ...................................... | | 6 |
| 1. Representative of the Midford Sands ........................ | 3 | 6 |
| The Upper Lias. | | |
| | 28 | 0 |

The Midford Sands are represented by an arenaceous stratum, samples from which give no reaction with hydrochloric acid. Then follows a light-coloured limestone, 6 inches thick, which appears to have escaped the notice of previous observers. Thin sections of it prove that the limestone is crystalline, and for this reason some of the organic remains are not determinable. Among those which could be made out are the ossicles of crinoids, spines, shell-fragments, and

* 'Monograph of the British Jurassic Gasteropoda,' Pal. Soc. vol. xl. (1886) p. 19.

foraminifera. The first two are the most numerous, and the rock may be said to be largely made up of them.

Next follows the Cephalopoda-bed. It is $1\frac{1}{6}$ foot thick and is an argillaceous deposit containing belemnites.

Of the calcareous bed which follows no thin section could be made, and it will be referred to under the head of Insoluble Residues. This is succeeded by an argillaceous deposit containing *Rhynchonella cynocephala* at the base. The beds above are also fairly fossiliferous, and among them Mr. Buckman has determined the following *:— *Rhynchonella subangulata*, *Rh. subdecorata*, *Terebratula perovalis*, *T. Etheridgii*, and *Pholadomya fidicula*.

Above the last bed we come to about ten feet of argillaceous strata in which are calcareous nodules made up of fragments of spines, ossicles of crinoids, &c. The nodules are of the same yellow colour and of the same structure as the lowest limestones of the Inferior Oolite; they are in fact the first indications of the Inferior-Oolite limestones, and point to a gradual incoming of conditions which were ultimately favourable to the existence of calcareous organisms.

It is at the top of the argillaceous beds containing the nodules that the Transition Beds terminate, and coarse yellow limestones appear which I regard as the base of the Pea-Grit Series.

### (c) *The Pea-Grit Series.*

The term "Pea-Grit Series" will probably be challenged. The name was originally given by Mr. Hugh Strickland † to beds between the Midford Sands and Lower Freestones, and he describes them as "pisolite" and "ferruginous oolite." The term was generally accepted till it was objected to by the late Mr. Witchell ‡. He did so on the ground that the term Pea Grit, as defined by Strickland, has caused "confusion" §: this because in the Stroud area the large grains of the Pea Grit come in suddenly and show a well-marked dividing-line between the pisolite and the oolite beneath. This is perfectly true, and to Mr. Witchell belongs the credit of pointing out the fact. But because beds differ lithologically in different localities there seems no sufficient reason for altering a well-known and accepted term.

The normal section of the Pea-Grit Series is seen at Leckhampton Hill, and in 1860 the late Dr. Wright, F.R.S., showed that there were three divisions, which he marked A, B, C. The lowest of these he described as "a coarse brown ferruginous rock, composed of large oolitic grains; it is readily disintegrated by the frost, and is of little economic value. About 20 feet thick" ‖. The fact is that this "coarse brown ferruginous rock" becomes less ferruginous

* Proc. Cottesw. Natur. Field Club, vol. x. (1889–90) p. 96.
† Quart. Journ. Geol Soc. vol. vi. (1850) p. 242.
‡ *Ibid.* vol. xlii. (1886) pp. 264–270.
§ *Tom. cit.* p. 246.
‖ *Ibid.* vol. xvi. (1860) p. 7.

and more oolitic in the Stroud area, but the Leckhampton-Hill section, as being the first described, should be regarded as normal for the Cotteswold area. In this paper I shall revert to the term "Pea-Grit Series," making it include the limestones which follow the Transition Beds and range up to the Lower Freestones. I shall justify this course as I proceed.

The lower beds of the Pea-Grit Series are exposed in No. 3 cutting on the Midland and South-Western Junction Railway east of Andoversford, where they rest on the "Transition Beds." They consist of coarse yellow limestone with occasional argillaceous bands, and may be taken at not less than 20 feet, but the exact thickness is doubtful on account of one or two small faults. Thin sections of these limestones show that they are made up of fragmentary organic remains, chiefly those of echinodermata, among which the ossicles of crinoids are the best preserved (Pl. XX. fig. 1); foraminifera, polyzoa, and the valves of ostracoda are also found in them.

Proceeding higher in the series we notice that the beds become thicker and contain large oolitic granules. Examined in thin sections under a microscope, the limestones are seen to be of much the same structure as those to which reference has just been made at the base of the series, but there is one important difference: it is that many of the organic fragments are surrounded with a crust (Pl. XX. fig. 2), and this crust is found to consist of the tubules of *Girvanella pisolitica*. Fragments so surrounded are the oolitic granules noticed in the rock. The beds continue to become more oolitic and the granules increase in size, but what I term the typical Pea Grit does not occur in No. 3 cutting above mentioned. Some of the beds, however, contain small pisolites.

With the above series are one or two argillaceous beds, and to one of these I desire to call special attention. It is characterized by the presence of calcareous sponges and polyzoa, and it is so well defined by these fossils that I feel justified in naming it the Sponge Bed. It is $1\frac{2}{3}$ foot thick, and besides the sponges and polyzoa contains numerous belemnites and shell-fragments, the latter for the most part badly preserved. The sponges have been submitted to Dr. G. J. Hinde, F.G.S., who has kindly determined them as follows:—*Lymnorea mamillosa*, Lam., *Lymnorea ramosa*, Hinde, and *Peronella tenuis*, Hinde.

The locality known as the Horsepools is on the crest of the Cotteswold Hills, between Gloucester and Stroud. The actual junction with the sands is not exposed, owing to the fact that the Transition Beds are useless for commercial purposes and consequently are not opened out. Mr. W. C. Lucy, F.G.S., kindly accompanied me to a quarry in which strata typical of the district were exposed. They consist of yellow limestones which are the equivalents of the Pea-Grit series in No. 3 cutting already alluded to.

*Section at Huddingknoll-Hill Quarry, Horsepools, near Gloucester.*

| | ft. | in. |
|---|---|---|
| 5. Dapple Bed | 1 | 0 |
| 4. Red Bed | | 10 |
| 3. Bastard Freestone | 2 | 6 |
| 2. Hard Brown Stone | 3 | 0 |
| 1. Rockery Bed | 4 | 0 |
| | 11 | 4 |

It will be observed that each bed has a name: these have been given by the local quarrymen, a fact which shows that each bed has it distinctive features. The following are the facts derived from microscopical examination:—

The Rockery Bed is a limestone made up of small fragments of echinodermata, chiefly the ossicles of crinoids, portions of shells, spines, and foraminifera. No oolitic granules were detected.

The Hard Brown Stone contains organic remains similar to those in the last bed, but larger. To some few the tubules of *Girvanella* are attached, a feature not noticed in the Rockery Bed. There are also some very small, highly-crystalline oolitic granules of the ordinary type.

The Bastard Freestone is a limestone in which the organic fragments are larger than those in the beds below, and many of them are enclosed in a crust consisting of the tubules of *Girvanella pisolitica* and so form oolitic granules; hence the name "Bastard Freestone."

The Red Bed takes its name from the colour, which is due to ferric oxide. The limestone is more crystalline than those before mentioned, and there is a considerable amount of infilling calcite. The organic fragments are small, about the size of those in the Rockery Bed, but in this case they mostly served as nuclei for oolitic granules.

The Dapple Bed is so named by the quarrymen because it is marked by light and yellow patches, a feature which attracted the notice of geologists some years ago. Mr. W. C. Lucy, in his very interesting "History of the Cotteswold Naturalists' Field Club," records (p. 6) that on October 6, 1849, the Club met at the Horsepools, and in the Huddingknoll Quarry Mr. Strickland "called attention to some quartz pebbles embedded in the Oolite, and also to pebbles of Oolite in a bed distinguished from the matrix in which they were enclosed by a difference in colour and texture, thus evidencing the destruction of older rocks of the same nature during or previous to the deposition of the existing Oolitic Rocks."

The Dapple Bed is the highest one of the Pea-Grit Series exposed in Huddingknoll-Hill Quarry. I have not seen the typical Pea Grit exposed in this neighbourhood; but, judging from pieces picked up in old quarries now partially filled in, I believe that it does occur in the district.

As representing the Pea-Grit Series in the Stroud area specimens

were collected from Horns Valley Quarry. The following is a vertical section:—

*Section of the Pea-Grit Series exposed in Horns Valley Quarry, near Stroud.*

| | ft. | in. |
|---|---|---|
| 6. Coarse Oolite | 12 | 0 |
| 5. Variable Argillaceous Bed | 1 | 0 |
| 4. Hard Cream-coloured Bed | | 10 |
| 3. Coarse White Oolite | 5 | 0 |
| 2. Typical Pea Grit | 3 | 0 |
| 1. White Oolite | 10 | 0 |
| | 31 | 10 |

Referring to the beds below the typical Pea Grit in the neighbourhood of Stroud, the late Mr. Witchell observed that * "one of the beds. . . . is remarkable for its great thickness; in several quarries it varies from 10 to 15 feet, a feature quite unusual in the lower Oolites and is altogether different from the pisolitic character, which is that of a rubbly rock." My examination of that bed quite confirms Mr. Witchell's description. Thin sections show it to be a regular freestone and somewhat crystalline.

Bed No. 2 is what may be called the typical Pea Grit. The bed is about 3 feet thick, and is made up of pisolitic granules, which vary from 3 to 7 mm. in diameter. The feature which distinguishes this bed is the weathering out of the pisolitic spherules or granules. These resist the weathering better than the matrix in which they occur, and hence stand out in relief after exposure to the atmosphere for a time.

Bed No. 3 is a coarse white oolite, and thin sections show that the coarseness is really due to granules which may almost be called pisolites. In some of these the tubules of *Girvanella pisolitica* are seen, but in others a very much swollen tubular structure (which corresponds with that in the Coralline Oolite at Weymouth) is noticed.

Bed No. 4 is a hard cream-coloured limestone which contains pisolites; the latter vary in diameter from 3 to 4 mm., and are therefore smaller than those in the typical Pea Grit. Most of these pisolites appear to be formed by the minute tubules to which reference has been made.

Bed No. 5 is an argillaceous bed, and will be referred to in Part II. of this paper.

Bed No. 6 consists of about 12 feet of coarse oolite in bands of from 2 to 3 feet thick. Thin sections show the limestone to be chiefly made up of small oolitic granules of the ordinary type and also a few pisolites in which the tubules of *Girvanella* are noticed. These latter beds are near the base of the Lower-Freestone Series, but the Coral Bed, to which I shall presently refer as the base of the Lower Freestones, is not exposed.

* Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 267.

I have confirmed Mr. Witchell's statements as to the freestone character of the beds below what I have termed the "typical Pea-Grit Bed;" my sections, however, show that the pisolitic structure is not confined to that particular bed, but that it continues up to the top of the quarry from which my sections were taken. I therefore claim that the term Pea-Grit Series may be rightly retained, and that the oolite below the "typical Pea Grit" must be included.

I now pass to the extreme north of the area under consideration, namely, to Cleeve Hill, the highest elevation of the Cotteswold Hills. Here again the Transition Beds are not exposed; the beds which are seen are those of the Pea-Grit Series, but probably not the lowest beds.

The following is a detailed section of the Pea-Grit Series at Cleeve Hill; most of the measurements were taken in conjunction with Mr. S. S. Buckman, F.G.S. Comparing the section with those of the corresponding beds at the Horsepools and at Stroud, the greater development of the Pea-Grit Series towards the north becomes apparent:—

*Section of the Pea-Grit Series at Cleeve Hill, near Cheltenham.*

Polyzoa Bed, base of the Lower-Freestone Series.

| | ft. | in. |
|---|---|---|
| 26. Yellow Limestone | 3 | 3 |
| 25. Yellow Argillaceous Bed | 2 | 0 |
| 24. Yellow-brown Arenaceous Bed | 2 | 3 |
| 23. Argillaceous Bed | 3 | 0 |
| 22. Yellow Limestone. Small oolitic granules | 5 | 0 |
| 21. Hard Oolitic Limestone | | 6 |
| 20. White Limestone. Oolitic granules | 3 | 0 |
| 19. Typical Pea Grit | 3 | 6 |
| 18. Yellow Argillaceous Partings. Pisolites | | 10 |
| 17. White Limestone. The topmost 8 inches contain pisolites | 7 | 6 |
| 16. Yellow-grey Limestone | 2 | 6 |
| 15. Typical Pea Grit | 4 | 6 |
| 14. Grey Limestone. Some pisolites | 3 | 4 |
| 13. Grey Limestone with shell-fragments and a few pisolites. | 1 | 6 |
| 12. Hard Brown Limestone | | 10 |
| 11. Coarse Limestone | 1 | 4 |
| 10. Light Brown Limestone. A few pisolites | 1 | 0 |
| 9. Soft Brown Limestone | | 7 |
| 8. Brown Limestone | | 8 |
| 7. Light Brown Limestone | | 2 |
| 6. Grey Limestone | | 3 |
| 5. Light Limestone with yellow patches | | 7 |
| 4. Brown Limestone. Small pisolites | | 7 |
| 3. Coarse Limestone | | 6 |
| 2. Coarse Yellow Limestone | 1 | 2 |
| 1. Light Limestone | 1 | 8 |
| | 52 | 0 |

I have given the above detailed section for the reason already stated and also for the purpose of defining clearly the position of the beds which I select for microscopic examination.

Bed No. 3. The first glance at the slide containing the specimen

from this bed shows that the limestone has a structure different from that observed in the freestone below the typical Pea Grit at Stroud. Some of the fragments are seen to be thickly coated with the tubules of *Girvanella pisolitica* in a good state of preservation, while other fragments are free from it. Among the fragments portions of echinodermata (especially the ossicles of crinoids), shells, and foraminifera were noticed. With regard to those coated with the tubules of *Girvanella pisolitica*, this observation corresponds with what I have found in the upper portion of the same series in No. 3 railway-cutting east of Andoversford.

Beds Nos. 5 and 11 are similar to No. 4.

Bed No. 12. This bed shows no sign of *Girvanella pisolitica* and is a true crystalline oolite. The granules show the radial structure, and in some the concentric is apparent; in others there is only the dark granular structure. The spaces between the granules are filled in with clear calcite.

Bed No. 15 is one of the typical Pea-Grit Series, and is made up of the large pisolites which stand out in weathered specimens. Thin sections show that the spherules are those of *Girvanella pisolitica.*

Bed No. 17 is 7½ feet thick, and, with the exception of the uppermost 8 inches, contains no pisolites. A thin section of the limestone from about the centre proves it to be made up of crystalline oolitic granules, in some of which a faint tubular structure could be distinguished. A thin section of the rock taken from the uppermost 8 inches shows that some of the organic fragments are enclosed by the tubules of *Girvanella pisolitica* ; the fragments thus coated constitute the small pisolites.

Bed No. 19 is another bed of typical Pea Grit.

Bed No. 20 is 3 feet thick and full of oolite granules of the ordinary type. Mounted in Canada balsam these show the usual concentric structure, with streaks of calcite and a dark granular appearance. This oolite is one of the few which I have been enabled to polish, and in thin sections so prepared the concentric arrangement noticed in the ordinary preparations is much less apparent (Pl. XX. fig. 3). The object shows a dark granular crust around the nucleus, which is studded with spots and streaks of calcite.

Above this bed no pisolites appear, and the strata assume a freestone character. The line between the Pea-Grit Series and the Lower Freestones, which follow, might be drawn at Bed No. 21, but it is more convenient to do so at a few feet above, at what Mr. S. S. Buckman and myself have called the "Polyzoa Bed." It is characterized by the number of polyzoa which it contains, and may perhaps be represented in the Southern Cotteswold area by the well-known Coral Bed which occurs at that horizon.

### (d) *The Building Freestones.*

The middle division of the Inferior Oolite in the Cotteswold area consists of freestones, which are divided by the so-called Oolite Marl into the Lower and Upper.

*The Lower Freestone.*—This development of the Inferior Oolite is best seen in the fine exposure at Leckhampton Hill, where the Lower Freestone, according to Mr. Witchell *, is 110 feet thick. It is not well suited for microscopic examination on account of its crystalline nature. Thus Mr. Witchell remarks that "attempts have been made to discover traces of organisms in the nuclei of the oolitic granules, but without success, and the centre is generally of the same constitution as the envelope" †. Among the organic remains which could be determined, both as nuclei and free, are polyzoa, spines, and fragments of shell. The remains of echinodermata, so numerous in the Pea-Grit Series, are scarce in the Lower Freestone.

As to the origin of the oolitic granules, I have little to add to what I stated in a previous paper ‡. It is, however, safe to say that in some of them tubules are apparent, but in the majority there is very little structure to be seen, owing to the crystalline condition into which the granules have passed.

*The Oolite Marl* will be referred to under the head of Insoluble Residues.

*The Upper Freestone.*—Specimens from this division of the Inferior Oolite can generally be distinguished from the Lower Freestone by their greater compactness; that is to say, they are more oolitic and contain few organic fragments which do not serve as nuclei for oolitic granules. The beds are also less crystalline. In my previous paper § I have at some length referred to this Upper Freestone and pointed out that in Chedworth Wood, about 10 miles east of Cheltenham, there are blue patches of this freestone intermingled with the normal yellow. In this latter the organic origin of the granules is undoubted, for the *Girvanella* tubules are clearly seen in several instances. With regard to the yellow freestone I could not then speak so decidedly, but I have since made a further study of it and am now prepared to say that the granules, both in the yellow and in the blue rock, are of organic origin. This is indeed what might be expected, seeing that one variety of the freestone graduates into the other.

The Upper Freestone exposed in Chedworth Wood terminates in an argillaceous deposit 8 inches thick, which will be described under the head of Insoluble Residues.

### (e) *The Ragstones.*

The Ragstones constitute the Upper Division of the Inferior Oolite, and are better exposed in a recently-made cutting in Chedworth Wood than in any other part of the Cotteswold area. The following is a stratigraphical section showing the series of beds:—

* 'Geology of Stroud,' p. 46. † *Ibid.* p. 45.

‡ Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 275.

§ *Tom. cit.* p. 276.

*Section of the Ragstones, Chedworth Wood.*

| | ft. |
|---|---|
| *Clypeus Plotii* Beds | 8 |
| Grey Limestone | 12 |
| Gryphite Grit | 22 |
| | 42 |

The Gryphite Grit is crowded with the bivalve *Gryphæa sublobata*, embedded in a dark limestone. Thin sections of this under a microscope show numerous well-preserved remains of polyzoa, of shells and fragments of echinodermata, with a quantity of calcite. Polyzoa have evidently contributed largely to the limestone.

Next in ascending order comes about 12 feet of grey limestone. The top beds of this probably represent the so-called Upper *Trigonia* Grit of some geologists. Thin sections under a microscope show it to be made up of a variety of organic fragments, including foraminifera, echinodermata, ostracoda, portions of shells, and a quantity of infilling calcite. There are also a few oolitic granules present, in which tubules of *Girvanella* were noticed.

Then come the *Clypeus Plotii* Beds. They consist for the most part of a loose argillaceous oolite, in which are numerous specimens of the sea-urchin, *Clypeus Plotii.* The oolitic granules are large and of organic origin, the tubules of *Girvanella* being frequently distinguishable.

The Ragstones terminate the Inferior Oolite and are overlain by the Fuller's Earth.

## Part II.—Insoluble Residues.

### (a) *Details of Residues in the Beds referred to in Part I.*

The residues were obtained by treating some of the rock with strong hydrochloric acid in a small flask. After the evolution of carbon dioxide had ceased, the flask was placed on a tripod and the contents boiled. This having been done, the residue was allowed to subside; the solution was then poured off, and the residue washed three or four times with distilled water, and allowed to subside after each washing. It was next transferred to a platinum dish or a watch-glass, and dried in a hot-air oven. When working on the Oolite Marl and the argillaceous bed at the top of the Upper Freestone at Chedworth, a modification of this process was adopted, which will be explained in a later portion of this paper.

As far as possible I have taken the residues from the same beds and in the same order that I have the thin section in Part I.

*The Transition Beds.*—The specimens examined were collected from No. 3 cutting east of Andoversford, on the Midland and South-Western Junction Railway. A section of the beds is given on p. 551.

No. 1. This, the representative of the Midford Sands, yielded 88 per cent. of residue insoluble in hydrochloric acid. This insoluble residue consisted chiefly of quartz, jagged flakes of mica, some zircon and felspar.

No. 2. The crystalline limestone above the "Sands." It yielded only 9·9 per cent. of residue, which, like that from the previous bed, contained quartz, felspar, occasional grains of zircon, some little mica, and one fragment of tourmaline.

No. 3. The Cephalopoda-bed gave 31·1 per cent., made up chiefly of some well-preserved felspar, a little zircon, and mica. Some of the grains contained inclusions.

No. 4. This 10-inch bed yielded 11·1 per cent. of residue, consisting of quartz associated with felspar and some zircon.

No. 5. The 12 feet of irregular bedded material yielded 46·8 per cent. of insoluble residue, made up of quartz, felspar, and zircon. Some of the felspars are remarkably well preserved.

No. 6. The 10 feet of strata at the top of the Transition Series yielded 42·8 per cent. of residue, in which quartz predominates; felspar was present. This residue also contains flakes of a dark granular substance, which proved to be coagulated silicate of alumina.

*The Pea-Grit Series.*—The amount of residue in the beds of the Pea-Grit Series (railway-cutting E. of Andoversford) shows a great falling off compared with the Transition Beds. An estimation in a typical specimen gave 2·1 per cent., a result which was quite consistent with those obtained from corresponding beds in other localities. The residue consists almost entirely of grains of quartz, averaging 0·17 mm. in greatest diameter.

It will be remembered that the lowest exposure of the Pea-Grit Series at the Horsepools is that of beds on the horizon of the Pea-Grit Series below the typical bed. A vertical section of these beds has already been given on p. 554, and residues were obtained and examined from the following:—

Bed No. 2. Hard Brown Stone. Contains 4 per cent. of residue, mostly quartz-grains, averaging 0·24 mm. in diameter. One fragment of felspar was noticed.

No. 3. Bastard Freestone. Yields 3·3 per cent. of quartz and some mica.

No. 4. Red Bed. Gives 10·2 per cent. of residue, mostly of well-rounded quartz (Pl. XX. fig. 5) as large as 0·49 mm. in diameter.

A section showing the position of the beds of the Pea-Grit Series in the Stroud area is given on p. 555.

Two estimations of the quantity of residue in the 10 feet of freestone below the typical Pea Grit gave 7·5 and 4·9 per cent. respectively. The freestone contains well-rounded grains of quartz, averaging 0·17 mm. in diameter, one of which shows an inclusion, apparently of rutile. Felspar is also noticed.

The typical bed of Pea Grit yields 5·7 per cent. of residue, and is remarkable for the large amount of cryptocrystalline silica which it contains. This is in the form of casts (Pl. XX. fig. 4) of organic structures which occur in the rock. Putting aside these casts, the detrital material appears to be remarkably small, and consists for the most part of quartz, minute flakes of mica, and some felspar.

Bed No. 3 gives 3·7 per cent. of residue consisting of quartz and some zircons.

Bed No. 5 yields 4·6 per cent. of residue consisting of quartz, felspar, and small flakes of mica.

Bed No. 6 yields 1·7 per cent. of quartz, with some felspar, zircon, mica, and a little cryptocrystalline silica.

For the beds selected for examination at Cleeve Hill, see the vertical section of the Pea-Grit Series on p. 556.

Bed No. 5 yields 5·5 per cent. of residue made up of quartz, flakes of mica, silicate of alumina, cryptocrystalline silica, and a number of microscopic quartz-crystals with sharply defined faces (Pl. XX. fig. 6). They appear in the form of prisms capped by pyramids and contain numerous inclusions. The crystals seem to have originated from the cryptocrystalline silica and silicate of alumina, and the inclusions in the crystals appear to be portions of the latter substance. There are also other crystals present of a very different origin. These are *reconstructions* around an original crystal of quartz, the faces of which have been worn off apparently by water-action. These forms are similar to those I have described and figured * from the Carboniferous Limestone of Clifton, near Bristol.

This residue also included some free detrital quartz-grains with an average diameter of 0·16 mm.; in one instance an inclusion of zircon was noticed.

No. 6. This bed gives 0·4 per cent. of residue, mainly of detrital quartz, with some felspar and zircon.

No. 15. This typical Pea Grit contains a residue of quartz, small scales of silicate of alumina, and some felspar. A comparison with the residue obtained from the typical bed at Stroud shows that the cryptocrystalline silica, so prominent a feature in that residue (see p. 560), does not occur in this.

Bed No. 17 yields 0·6 per cent. of residue, in which quartz, felspar, and zircon are the chief constituents.

Bed No. 19. This is the second bed of typical Pea Grit. It has 3·6 per cent. of residue, which corresponds with that from the bed at Stroud in the quantity of casts of cryptocrystalline silica it contains. The residue also shows quartz and well-preserved felspar.

Bed No. 20 yields 0·2 per cent. of residue, of which quartz-grains, with some felspar, rutile, and zircon, are the chief constituents.

Bed No. 24. This is a sandy bed. It gave 8 per cent. of residue, chiefly quartz.

*The Lower Freestone.*—As before remarked, I regard the Polyzoa Bed at Cleeve Hill and the Lower Coral Bed in the Southern Cotteswolds as the base of the Lower Freestone.

At Cleeve Hill the Polyzoa Bed contains 3 per cent. of residue, chiefly detrital quartz-grains as large as 0·3 mm. in their longest diameter, but averaging about 0·22 mm. Well-preserved fragments of felspar, including microcline, are also present.

The Coral Bed at Crickley Hill, near Gloucester, gave 3·2 per cent. of residue, consisting of quartz, felspar, and rutile (?).

* Quart. Journ. Geol. Soc. vol. xliv. (1888) pl. viii. figs. 3 & 4.

Specimens of the Lower Freestone proper were collected at Leckhampton Hill, near Cheltenham.

No. 1, from near the base of the series, yielded 0·8 per cent. of quartz-grains, the grains as large as 0·16 mm. in their longest diameter, and averaging 0·13 mm. One or two fragments of felspar and some zircon were noticed.

No. 2 yielded 0·9 per cent. of residue, consisting almost entirely of quartz.

No. 3 gave 1·1 per cent. of quartz, with some little felspar and mica.

No. 4. The residue contains little else than quartz-grains, which average about 0·11 mm. in diameter.

*The Oolite Marl.*—The Oolite Marl is a well-marked boundary between the Lower and Upper Freestones in the Northern Cotteswolds. It attains its greatest development at Cleeve and Leckhampton Hills, near Cheltenham, where it appears as a yellow, calcareous, argillaceous deposit, about 7 feet thick. Specimens for examination were collected from Leckhampton Hill, and were taken from the bottom, middle, and top of the marl.

No. 1, from the base, contains 3·2 per cent. of residue, which, in the acid solution, is mostly a flocculent substance. When mounted on a slide and placed under a microscope, the most conspicuous constituents in the residue are scales suggestive of sericite, and for some time I so regarded them. This, however, was an error, arising out of the way in which I prepared the specimens for mounting. My method is, after washing free from calcium chloride, &c., to dry the residue on a watch-glass; but, not being satisfied about the supposed sericite, I removed a portion of the residue from the filter, and while moist spread it over a glass slide. In this the thin scales disappear, and the residue consists of an extremely fine granular substance, with very small flakes of mica and other doubtful mineral fragments. It was further discovered, when I dried the residue on a watch-glass, that the granular substance coagulated and enclosed some of the fine detrital material with it, especially the mica. This, then, was the origin of the supposed scales of sericite. The granular substance was afterwards proved to be chiefly silicate of alumina.

There is also another matter of interest connected with this silicate of alumina, to which Mr. Teall kindly called my attention. Examined under a high-power object-glass there is found to be associated with it a quantity of extremely minute crystals of rutile, corresponding exactly with those figured by Rosenbusch *, and to which Zirkel first called attention in clay-slates and roofing-slates; hence they have been termed "clay-slate needles" (*Thonschiefernadeln*).

Mr. W. M. Hutchings † has also shown that some Carboniferous argillaceous beds at Seaton contain what he terms "a sort of

* 'Microscop. Physiogr. of Rockmaking Minerals,' transl. Iddings (1888), pl. xv. fig. 4.

† Geol. Mag. (1890) p. 271.

groundmass or paste . . . . and throughout this paste immense numbers of rutile crystals are seen." This corresponds with the granular substance I have referred to as the chief constituent in the residue of the Oolite Marl.

Specimen No. 2 was collected from about the centre of the marl and contains 3·1 per cent. of residue. Like the last-mentioned, this consists chiefly of the granular silicate of alumina, and associated with it are small flakes of mica, quartz-grains, and a considerable quantity of very minute crystals of zircon. The quartz-grains averaged 0·08 mm. in longest diameter.

No. 3. This specimen was taken from the top of the marl. It yielded 3·5 per cent. of residue, chiefly flakes of mica, decomposed felspar, and quartz-grains, the latter averaging about 0·1 mm. in greatest diameter.

*The Upper Freestone.*—Two specimens were collected from the Upper Freestone at Leckhampton, where it is about 30 feet thick.

No. 1 yields 0·9 per cent. of residue, chiefly quartz-grains and pyrites, the latter sometimes in the form of minute spheres.

No. 2 yields 0·6 per cent., consisting of quartz-grains and mica.

A residue from these freestones at Cleeve contains quartz with felspar and a few crystals of zircon. The proportion of felspar was the chief feature of interest.

Specimens were also collected from the Upper Freestone exposed in Chedworth Wood, to which reference has been made in Part I. of this paper. It will be remembered that there were two varieties, the normal yellow and the blue. A specimen of the former yielded 0·8 per cent. of residue, consisting of quartz, a quantity of felspar, and some amorphous silica, chiefly in the form of casts of *Girvanella* tubules.

Of the blue variety two estimations of the residue gave 7·5 and 1·7 per cent. respectively. There is a considerable discrepancy between the two, and also between these and 0·8 per cent. obtained from the yellow oolite. This entirely arises from the varying proportion of pyrites in the respective residues. This sulphide of iron is more plentiful in the blue oolite, and where it occurs in considerable quantity, as in the case of the specimen which yielded 7·5 per cent. of residue, the rock soon crumbles on exposure to the atmosphere—this, no doubt, owing to the oxidation of the pyrites. The sulphide of iron occurs chiefly in a spherical form, and there are either casts or replacements of the tests of foraminifera and other organisms.

*The Argillaceous Bed, which terminates the Upper Freestone at Chedworth.*—This bed yielded 67·9 per cent. of residue, consisting of quartz, some felspar, mostly decomposed, and mica. But the chief constituent of the residue is silicate of alumina, and it corresponds in every respect with that found in the Oolite Marl. In the bed at Chedworth this silicate of alumina occurs in such quantity that it was easy to obtain sufficient for chemical analysis, and, with the object of proving beyond doubt that it is a silicate of alumina,

an analysis was made with the following result, after drying at 212° F.:—

| | |
|---|---|
| Loss on ignition | 9·66 |
| Silica | 67·90 |
| Alumina with a trace of iron | 18·00 |
| Magnesia | 0·06 |
| Other constituents, by loss | 4·38 |
| | 100·00 |

The specimen was taken from the Barrow cutting on the Midland and South-Western Junction Railway near Chedworth.

As in the case of the Oolite Marl, there is associated with the Argillaceous Bed a quantity of very small mineral fragments, among which were the extremely minute crystals of rutile, known as the "clay-slate needles."

*The* Clypeus Plotii *Beds.*—A typical specimen from these beds near Chedworth gave 5 per cent. of residue consisting of quartz and felspar, some of the latter much decomposed. One crystal of zircon was noticed.

(b) *General Summary of the Residues.*

Taking the residues as a whole, they may be said to contain chiefly detrital quartz, and next in quantity felspars, zircons, tourmaline, and occasionally rutile. In the Horsepools district, the quartz-grains form almost the entire residue. The zircons may be said to be most plentiful in the Transition Beds; they occur in the form of short prisms and show no sign of water-action. In some beds the felspar is plentiful, and remarkable for the good state of preservation of the fragments. Both monoclinic and triclinic felspars are present, especially microcline. The micas occur in small jagged flakes, chiefly as muscovite. The quartz-grains are rounded, except in the case of very minute ones; and some contain inclusions.

Several residues from the limestones contain silicate of alumina in the form of scales, enclosing minute flakes of mica and quartz. These scales were, however, formed by the coagulation of the silicate during the process of drying the residue, a circumstance to which I have directed special attention when describing the Oolite Marl (see p. 562).

In the Argillaceous Beds, silicate of alumina is plentiful in the form of extremely minute granules. It would moreover appear from Bed No. 5 in the Cleeve-Hill section (Pl. XX. fig. 6) that silicate of alumina does undergo decomposition, the silica assuming an amorphous form which subsequently becomes crystalline. It may be, however, that the freed silica at first became soluble in water, and that it was redeposited in the amorphous form, which afterwards became crystalline.

It is in this way that I account for the siliceous casts of organic structures which occur in the typical Pea Grit, and in some beds of the Upper Freestone. I am disposed to regard these cryptocrystalline siliceous casts as derived from the decomposition of silicates,

and the freed silica as having become soluble in water, and as having been subsequently redeposited, either replacing the carbonate of lime forming the tests or skeletal structures of organisms, or infilling the spaces rendered vacant by the removal of organic matter as the result of decomposition. The evidence in support of this is the fact of the occurrence of silicate of alumina with the amorphous and cryptocrystalline silica.

There is another mineral seen in the residues to which as yet I have made no allusion. It occurs in the form of angular chips; they are isotropic, colourless, or slightly tinged with pink, and especially remarkable for their high order of refraction. Mr. W. M. Hutchings, in his article "Notes on the probable Origin of some Slates from the Cliffs near the Village of Seaton" *, says:—"The minerals which fell out were zircons, numerous and of rather large size, garnets in angular colourless fragments," &c. The part of this statement to which I desire to draw special attention is that which refers to the garnets. The description corresponds with the chips of that mineral in the residues, except that in some cases they are tinged with pink.

### (c) *Origin of the Residues.*

The detrital material now in the rocks cannot be taken to represent the quantity at first deposited. Chemical changes have taken place by which some original materials have been decomposed and others constructed. It is, therefore, only the most indestructible constituents of the original minerals which remain, and among these are grains of quartz. This is shown by the rounding action of the water, which is as clearly defined on the larger grains as at the time when it took place (see Pl. XX. fig. 5).

The quantity of felspar present in some residues seems to indicate that there must have been a considerable amount of felspathic minerals in the sediment. It is probably owing to the decomposition of these that the silicate of alumina in the strata has been derived and the argillaceous character of some beds is due.

The origin of the minute crystals of rutile noticed in the Oolite Marl and Argillaceous Bed at the top of the Upper Freestone at Chedworth is a question of considerable interest. Rutile is known to occur as a secondary product in some instances; but in this case I think the evidence is in favour of its having been derived as detrital material from other rocks, possibly in part as inclusions in other minerals. In support of this hypothesis I may point out that the quartz-grains in the Oolite Marl and Clay Bed only average 0·09 and 0·08 mm. in longest diameter respectively. It would seem probable, therefore, that the detrital material originally deposited was very fine, and it would be with this detrital material that the rutile would be carried. Other crystals might be expected to separate *in situ* by the decomposition of the minerals containing them as inclusions.

I regard the detrital residue as a whole as having been derived

* Geol. Mag. (1890) p. 266.

from crystalline felspathic rocks, and not from the denudation of stratified ones. The quantity of felspar and its state of preservation seem to support this view.

(d) *The Quantity of Residue and Size of the Quartz-grains.*

When describing the respective residues I have generally stated the quantity existing in the rock, but as this is an interesting and important point I propose to refer to it in greater detail. The following table gives the percentage of residue and average of quartz-grains in the Transition Beds:—

| | Percentage of Insoluble Residue. | Average size of Quartz-grains in mm. |
|---|---|---|
| The topmost 10 feet of the Calcareous Argillaceous Beds | 42·8 | 0·16 |
| Irregularly bedded argillaceous material | 46·8 | 0·17 |
| 10-inch Calcareous Bed | 11·1 | 0·16 |
| Cephalopoda-bed | 31·1 | 0·11 |
| Crystalline Limestone | 9·9 | 0·10 |
| Midford Sands | 88·0 | 0·09 |

The residues show a falling-off in quantity above the Midford Sands, a feature much more marked in the Pea-Grit Series, which follows the Transition Beds.

The following table gives the residue and size of quartz-grains in the Pea-Grit Series in the localities referred to in this paper:—

| | Percentage of Insoluble Residue. | Average size of Quartz-grains in mm. |
|---|---|---|
| *East of Andoversford.* | | |
| I. Limestone | 2·2 | 0·06 |
| II. " Pisolitic | 3·8 | 0·16 |
| III. " Coarse Oolite | 2·1 | 0·17 |
| *Horsepools District.* | | |
| IV. Hard Brown Stone | 4·0 | 0·24 |
| V. Bastard Freestone | 3·3 | 0·20 |
| VI. Red Bed (lowest exposed) | 10·0 | 0·20 |
| *Stroud District.* | | |
| VII. Bed No. 6 | 1·7 | 0·13 |
| VIII. " " 5, argillaceous | 24·5 | 0·13 |
| IX. " " 4 | 4·6 | 0·12 |
| X. " " 3 | 3·7 | 0·11 |
| XI. " " 2, typical Pea Grit | 5·7 | 0·18 |
| XII. " " 1 B | 4·7 | 0·17 |
| XIII. " " 1 A | 7·5 | 0·17 |
| *Cleeve Hill.* | | |
| XIV. Bed No. 24, arenaceous | 8·0 | 0·11 |
| XV. " " 20 | 1·1 | 0·15 |
| XVI. " " 19, typical Pea Grit | 3·6 | 0·17 |
| XVII. " " 17 | 0·6 | 0·15 |
| XVIII. " " 15 | 4·0 | 0·07 |
| XIX. " " 11 | 1·2 | — |
| XX. " " 3 | 5·5 | 0·06 |

On the whole the proportions of residue shown in the above table are low; the exceptions are Nos. XIV., XIII., VIII., and VI. Of these, No. VIII. is from an argillaceous bed, and would naturally give a high proportional residue.

The following tables give the percentages of residue in the Lower Freestone:—

| | Percentage of Insoluble Residue. | Average size of Quartz-grains in mm. |
|---|---|---|
| Leckhampton, No. 3 | 1·1 | 0·11 |
| " " 2 | 0·9 | 0·14 |
| " " 1 | 0·8 | 0·13 |
| Polyzoa Bed, Cleeve | 3·0 | 0·22 |
| Coral Bed, Crickley | 3·2 | 0·06 |

Excluding the Polyzoa and Coral Beds, the Freestones show a remarkably low percentage of residue. No. 3, Leckhampton, was taken from near the top of the Freestones, not far below the Oolite Marl. It will be noticed that there is an increase in the proportion of residue in that estimation, and a decrease in the size of the quartz-grains, thus indicating the coming in of the Oolite Marl.

The following table gives the percentage of residue in the Oolite Marl:—

| | Percentage of Insoluble Residue. | Average size of Quartz-grains in mm. |
|---|---|---|
| From the top | 3·5 | 0·10 |
| From the middle | 3·1 | 0·08 |
| From the bottom | 3·2 | 0·09 |

The term "marl" would lead us to expect larger residues than are shown in the above table, and in order to test the correctness of the estimations, and also to ascertain whether the marl contains much free alumina, I made an analysis which gave the following result:—

*Analysis of the Oolite Marl at Leckhampton.*

Dried at 212° F.

| | |
|---|---|
| Insoluble residue | 3·1 |
| Alumina, with trace of iron | 1·7 |
| Carbonate of lime | 94·4 |
| Carbonate of magnesia | 0·5 |
| Alkalies, by loss | 0·3 |
| | 100·0 |

The above analysis proves the correctness of the residue estimations. It shows also that there is very little free alumina present in the marl, and that 94·4 per cent. of the whole is calcium carbonate. The 3·1 per cent. of residue is chiefly silicate of alumina; it therefore appears that this small quantity is sufficient to give a marly character to the strata.

The following table gives the percentages of residue in the Upper Freestone:—

| | Percentage of Insoluble Residue. | Average size of Quartz-grains in mm. |
|---|---|---|
| I. Leckhampton | 0·9 | 0·11 |
| II. „ | 1·1 | 0·13 |
| III. „ | 0·6 | 0·12 |
| IV. Chedworth Wood | 1·5 | 0·14 |
| V. „ | 1·2 | 0·11 |
| VI. „ | 1·7 | 0·15 |

The percentages of residue from Leckhampton are low, and correspond closely with those in the Lower Freestone. The percentages from Chedworth are higher, but this is due to the presence of pyrites, which cannot be regarded as detrital material.

The following table gives the results from the Ragstones:—

| | Percentage of Insoluble Residue. | Average size of Quartz-grains in mm. |
|---|---|---|
| I. *Clypeus* Grit | 5·0 | 0·19 |
| II. Grey Limestone | 0·8 | 0·18 |
| III. Gryphite Grit, Chedworth Wood | 2·6 | 0·16 |
| IV. „ Leckhampton | 2·8 | 0·16 |

The *Clypeus* Grit shows a rather higher percentage of residue, compared with the Upper and Lower Freestones or even the Oolite Marl; in fact, there is a relatively higher residue throughout the Ragstones when compared with the Freestones. This is explained by the fact that the Ragstones underlie the Fuller's Earth, and therefore indicate the coming in of conditions which ultimately gave rise to that formation.

In order that we may the better compare the quantity of residue in the divisions of the Inferior Oolite, I give the following table of averages:—

| | Percentage of Insoluble Residue. | Average size of Quartz-grains in mm. |
|---|---|---|
| Ragstones | 2·8 | 0·17 |
| Upper Freestone, leaving out the blue variety. | 1·1 | 0·12 |
| Oolite Marl | 3·2 | 0·09 |
| Lower Freestone | 1·8 | 0·13 |
| Pea-Grit Series | 5·0 | 0·14 |
| Transition Beds | 38·3 | 0·13 |

The above table shows a great falling-off in the percentage of residue above the Transition Beds. That of the Freestones is remarkably low, and it would appear that these rocks were formed under conditions which allowed of very little sediment being deposited.

The size of the quartz-grains in the Transition Beds averages ·13 mm. There is a slight increase in the Pea-Grit Series, and a decrease in the Lower Freestone. The quartz-grains in the Oolite

Marl are very small; in the Upper Freestone they are nearly as large as those in the Lower Freestone, and in the Ragstones we get the largest size of any.

## EXPLANATION OF PLATE XX.

Fig. 1. Section of coarse limestone from near the base of the Pea-Grit Series. Shows it to be non-oolitic, and to be largely made up of the ossicles of crinoids and fragments of other echinodermata. × 12 diam.

2. Section of coarse semi-oolitic limestone from the Pea-Grit Series, a few feet above the spot from which the specimen represented in the previous figure was collected. It shows that some of the fragments in the rock are coated with a crust made up of the tubules of *Girvanella*. These are illustrations of the oolitic granules which appear in the beds. × 12 diam.
3. Section of what may be termed an ordinary oolitic granule from Bed No. 20 of the Pea-Grit Series at Cleeve Hill. The figure shows the granule as it appears in thin section, when simply polished, and not covered with Canada balsam. It shows a dark granular structure, with streaks and spots of calcite. The latter is infilling, and the whole is suggestive of a tubular structure, the outlines of which have been almost obliterated by molecular changes. × 70 diam.
4. Siliceous casts of organic structures in the "Typical Pea Grit" at Stroud. × 48 diam.
5. Grains of quartz from the Pea-Grit Series at the Horsepools, near Gloucester. × 18 diam.
6. Microscopic quartz-crystals formed *in situ*. They are associated with flakes of silicate of alumina and cryptocrystalline silica, from which they appear to have originated. × 40 diam. From Bed No. 5, Pea-Grit Series, Cleeve Hill, near Cheltenham.

## Discussion.

Prof. Hull gladly acknowledged the great amount of labour evinced by this paper on the part of the Author. When engaged many years ago in the geological survey of the Cotteswold Hills, he (Prof. Hull) had often felt the need there was for a microscopical examination of the Oolitic strata. Mr. Wethered had now supplied this want in a district which had been so ably illustrated as regards its palæontology by his distinguished relative, the late Dr. Wright. As regards the relations of the Upper Lias to the Inferior Oolite—as, for example, at Frocester Hill, where Dr. Wright had opened out his "Cephalopoda-bed"—it had always appeared to him that there was a very marked line of demarcation between the Upper-Liassic sands, with their peculiar fauna of *Ammonites*, and the basement beds of the Inferior Oolite; but, as the "transition" strata described by Mr. Wethered appeared to underlie the horizon of the Pisolite (or Pea Grit), he thought it probable that the *hiatus* was to some extent filled up by them, and that his views might not, after all, be so different as he had supposed from those of the Author.

Mr. Etheridge was glad to find that the Author was continuing his investigations into the petrological as well as the micro-zoological structure of the Oolites of the Cheltenham or Cotteswold-Hills area. The so-called "Transition Beds" between the sands of the

Upper Lias and the Pea-Grit Series appeared to have been very carefully studied by the Author with great detail. He hoped Mr. Wethered would continue his microscopical researches as to the intimate structure of the Lower Oolites, which would doubtless alter many views of sedimentation.

Mr. H. B. Woodward agreed with Prof. Hull that in general there was a fairly good divisional line between the Cephalopoda-bed and overlying Inferior Oolite, notwithstanding the fact that the original "Cephalopoda-bed" had been split up on palæontological grounds, and part of it put with the Inferior Oolite, and part with the Upper Lias. He maintained that the term "Midford Sands" was better than that of "Transition Beds" used by the Author. He believed, with Mr. Lucy, that there were pebbles of Oolite in some of the lower beds of the Inferior Oolite. The occurrence, in different layers of the same subdivision, of borings of Annelids and *Lithodomi*, showed that the Oolite had consolidated somewhat rapidly, and in such a false-bedded series it was not unlikely that some layers had been subjected to contemporaneous erosion. He asked the Author if he had found *Girvanella* in the matrix of any of the rocks, for the question was whether this organism had been a willing or unwilling agent in the formation of the Pea-Grit concretions; it had occurred to both Mr. Teall and himself that the *Girvanella* which was found coating the nuclei of the concretions might have been derived mechanically from the calcareous mud of the sea-bed.

The Rev. H. Winwood drew attention to the fact that the series of beds which the writer had such an opportunity of studying in the Cotteswold district did not exist in that near Bath. In some of the sections there, and notably in that at Midford, the sands were succeeded by a peculiar conglomeratic bed of Inferior Oolite, containing rolled phosphatic and other pebbles of a foreign rock which he should like Mr. Wethered to examine microscopically. *Rhynchonella spinosa* occurred in this bed.

The Author thanked the Meeting for the way in which his paper had been received. In reply to Prof. Hull and Mr. H. B. Woodward, he said that he did not propose to do away with the term "Midford Sands" nor with that of "Cephalopoda-bed." Terms introduced by William Smith and Dr. Wright should be respected. What he (the Author) contended was that these two beds, with others above them, belonged to a series which was transitional between the Upper Lias and Inferior Oolite. That being so, he failed to see why the beds occupying that position should not, as a whole, be identified by a term expressing true character, namely, Transitional Series.

With regard to the nature of *Girvanella*, he had that day shown some specimens to Mr. Geo. Murray at the Natural-History Museum, South Kensington, and that gentleman had given him permission to say that the structure was certainly organic. As to whether it was vegetable or animal, Mr. Murray was in doubt, but the fact that the tubes occur in dense compact wefts and never appear to anastomose seemed to him to dispose of the view that they belonged to a perforating Alga such as *Gomontia*, &c., recently described by M. Bornet.

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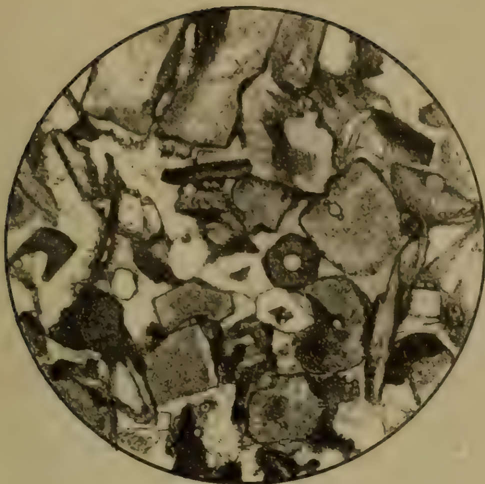

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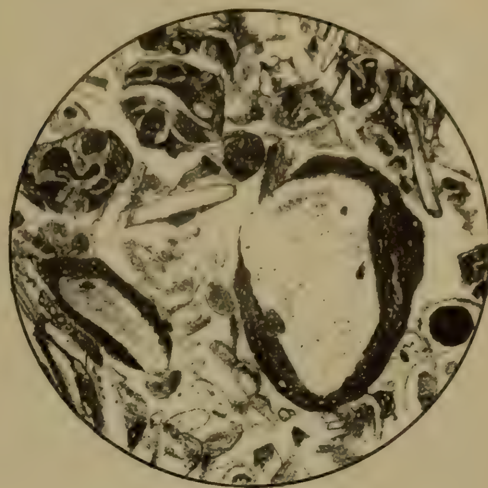

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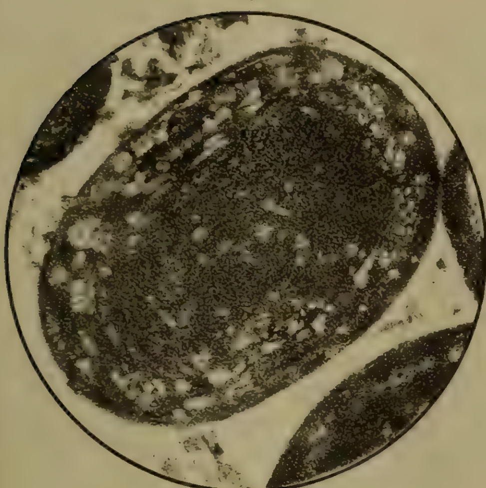

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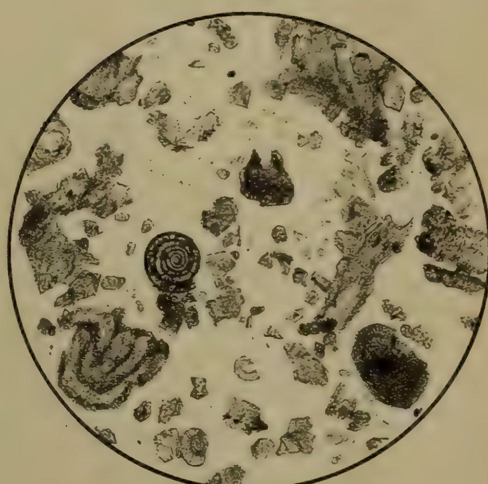

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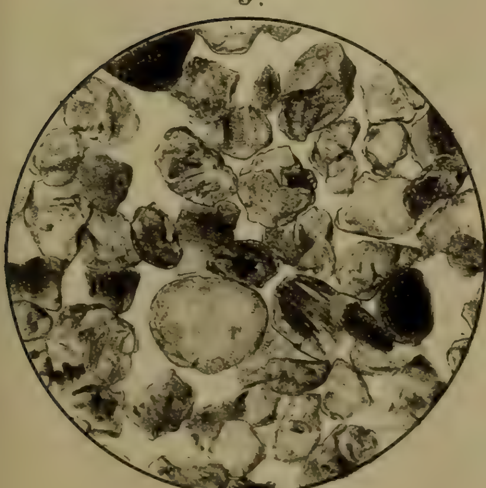

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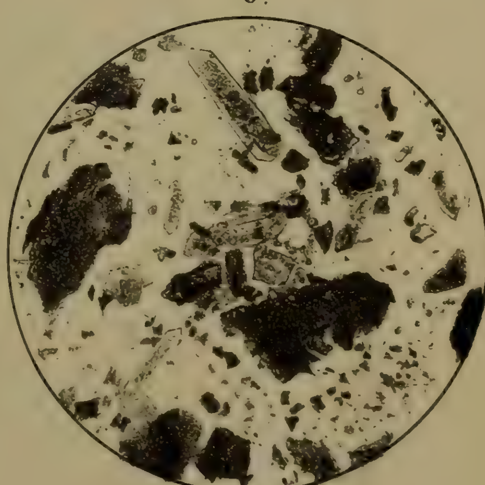


F.H. Michael del. et lith.

Mintern Bros. imp.

ROCK SECTIONS FROM THE INFERIOR OOLITE OF THE COTTESWOLDS.

## 32. *On* Lower Jaws *of* Procoptodon. By R. Lydekker, Esq., B.A., F.G.S. (Read May 27, 1891.)

[Plate XXI.]

The genus *Procoptodon* was established in 1874 by Sir R. Owen * for the reception of certain large extinct Kangaroos from the Pleistocene of Australia—distinguished among other features, by the firmer union of the mandibular symphysis in the adult, the shortness and depth of the whole mandible, and the relatively small length of the diastema. Moreover, the premolars are characterized by the shortness and thickness of their crowns; the true molars are long, and usually have their enamel thrown into a series of vertical folds; while the lower incisors differ from those of living Kangaroos in having cylindroidal crowns.

Sir R. Owen recognized three species of *Procoptodon*, viz. *P. Goliah*, founded upon a fragment of the upper jaw originally described as *Macropus Goliah* †; *P. Rapha*, typified by a fragment of an immature mandible ‡; and *P. pusio*, determined upon the evidence of a somewhat immature and imperfect palate §. It will thus be seen that only the types of *P. Goliah* and *P. pusio* are strictly comparable with one another. In the memoir in the Phil. Trans. numerous other imperfect upper and lower jaws were, however, described and figured and referred to the several species. The type of *P. pusio* is in the British Museum (No. 39996); but there is no record as to what has become of those of the other two species.

The true type of *P. Rapha*, being an immature specimen, is totally unfitted to afford specific characters, and indeed never ought to have been taken as a type. I have, therefore, considered it advisable to regard the imperfect right mandibular ramus figured in the Phil. Trans. for 1874, pl. lxxvii. (of which there is a cast in the British Museum, No. M. 3676), as representing this species, although there is no decisive evidence that it is distinct from *P. Goliah*. Much the same observation will apply to the type of *P. Goliah*, which likewise affords no well-marked specific characters.

In part v. of the 'Cat. Foss. Mamm. Brit. Mus.' p. 235, I considered that the type of *P. pusio* could not be specifically separated from *P. Rapha*, as represented by the mandible just mentioned; and the former was accordingly regarded as a synonym of the latter species. I considered, however, that the form described by Sir R. Owen as *Pachysiagon Otuel* ‖ represented another and smaller species of *Procoptodon*.

* Phil. Trans. for 1874, p. 788.

† Waterhouse's 'Mammalia,' vol. i. (1846) p. 59.—Figured in Phil. Trans. for 1874, pl. lxxix. fig. 4.

‡ Phil. Trans. for 1874, pl. lxxvii. figs. 8–11.

§ *Ibid.* pl. lxxvii. figs. 2–6.

‖ *Ibid.* p. 784.

Three species—*P. Goliah*, *P. Rapha*, and *P. Otuel*—were, therefore recognized in the 'Catalogue.' The third being much smaller and totally different from either of the others will need no further notice here.

With regard to *P. Goliah* and *P. Rapha*, it appeared to me that the latter was mainly distinguished from the former by its inferior dimensions, and it was accordingly suggested that the one might prove to be merely a smaller race of the other.

Recently I received, among other specimens, from the Commissioners of the Exhibition of the Mineralogical Products of New South Wales (held in the summer of 1890 at the Crystal Palace), two mandibular rami of *Procoptodon* obtained from the clay-beds near Miall Creek, in the neighbourhood of Bingera, on the northern frontier of New South Wales *. These specimens evidently belonged to two large-sized species of the genus, and I have accordingly been led to reconsider the evidence as to the specific distinctness of *P. Rapha* from *P. Goliah*. The result of my comparison of these specimens with the lower jaws in the British Museum is to show conclusively that this part of the skull indicates two very distinct species of large Procoptodons; but that there is the almost insuperable difficulty of determining to which of the two species they should respectively be referred, assuming that the types on which these species were established are specifically distinct from one another. I also conclude that differences of size are of very little importance in the discrimination of the two species,—both types of lower jaw indicating larger and smaller individuals, which may represent either sexual or racial differences.

I will first take the left ramus represented from the inner side in Pl. XXI. fig. 1. This specimen shows the whole series of cheek-teeth, which have been proved to be the permanent ones by chiselling away the outer side of the jaw below the first molar, and thus revealing the absence of a replacing premolar. The extremity of the symphysis is wanting; and the greater part of the hinder region is unfortunately absent. This specimen is characterized by its great depth, especially at the anterior extremity; and also by the deep and distinct channel between the last two molars and the ascending ramus. The characters of this mandible are very similar to those of the right ramus figured by Sir Richard Owen in the Phil. Trans. for 1874, pl. lxxvii., as *P. Rapha* (cast, B.M. No. M. 3676), although the Bingera specimen is somewhat the larger. The British Museum possesses another and almost entire mandible † (No. 46836) of the same type, which is of extreme importance as affording specific characters. The dimensions of these three specimens are as follows:—

* An account of these deposits will be found in the Proc. Roy. Soc. vol. xlix. pp. 61, 62.

† Figured in Owen's 'Extinct Mammals of Australia,' pl. cxxviii., as *P. Rapha*.

| | Bingera sp. inches. | No. 46836. inches. | No. M. 3676. inches. |
|---|---|---|---|
| Length of last 2 molars .... | 1·83 | 1·75 | 1·5 |
| " " " 4 " .... | 3·15 | 3·07 | 2·86 |
| " " cheek-series .... | 3·7 | 3·6 | 3·4 |
| Greatest depth at symphysis. | 2·6 | 2·4 | 2·2 |
| " width of jaw ...... | 1·9 | 1·8 | 1·85 |

These differences in size are obviously not such as can be considered of specific importance. One of the distinctions between *Procoptodon* and *Macropus* is the circumstance that the outer wall of the masseteric fossa extends much higher up in the former than in the latter, its summit reaching above the level of the molars, and thus converting the fossa into a complete "pocket." The specimen No. 46836 shows that the aperture of this "pocket" was comparatively small. Both the latter specimen and No. M. 3676 (Phil. Trans. for 1874, pl. lxxvii.) also show that the small inflected "angle" of the mandible was situated considerably below the level of the molar series, and likewise that there is a marked ridge extending upwards and backwards from behind the last molar, so as to separate the channel lying on the outer side of the molars from that part of the surface of the jaw situated above the "angle." All the three specimens agree in having the premolar of moderate length.

A fragmentary left mandibular ramus, of which there is a cast in the British Museum (No. M. 3674), containing the last two molars, is described and figured by Owen in the Phil. Trans. for 1874, pl. lxxix. fig. 8, and pl. lxxx. figs. 3–7, and referred to *P. Goliah*. Although slightly larger than the Bingera specimen, this jaw agrees, however, with the latter in the form of the extended molar channel; while its great thickness indicates that when entire it had the same excessive relative depth. The length of the two molars of this specimen is 1·95 inch, and its greatest breadth 2·1 inches.

The resemblance to the Bingera specimen is, indeed, so close as to forbid specific separation; and we thus have a complete gradation in point of size from this large jaw to the small No. M. 3676. We may agree, therefore, to call all these four specimens provisionally *P. Rapha*; although as regards the size of the largest there is no reason for separating them from *P. Goliah*.

I now come to the second type of mandible from Bingera, which is represented in Pl. XXI. figs. 2 & 2*a*. The specimen is a right ramus, which has lost the crowns of the first three cheek-teeth, but in which the whole of the masseteric fossa is beautifully preserved. A comparison of this specimen with the one represented in fig. 1 of the plate will at once show that it is distinguished by the greater relative length and much smaller depth of the horizontal ramus. A comparison with the British Museum specimens Nos. 46836 and M. 3676 reveals further points of difference. Thus the aperture of the masseteric "pocket" (fig. 2*a*) is very much larger in the present specimen; the "angle" (fig. 2, *an.*) is very large, and situated in the line of the molars; while there is no well-marked channel between

the molars and the ascending ramus. Moreover, the surface of the jaw external to the last molar is separated from the surface above the "angle" by a much less sharply defined ridge than that which occurs in *P. Rapha*. An imperfect but rather larger right mandibular ramus (B. M. No. M. 1897) is figured by Owen in the Phil. Trans. for 1874, pl. lxxx. figs. 1, 2, where it is referred to *P. Goliah*. The dimensions of these two specimens are as follows:—

| | Bingera sp. inches. | No. M. 1897. inches. |
|---|---|---|
| Length of last 2 molars ........ | 1·8 | 1·83 |
| ,, ,, ,, 4 ,, ........ | .. | 3·45 |
| ,, ,, cheek-series ........ | 3·55 | |
| Greatest depth at symphysis .... | 1·9 | 1·85 |
| ,, width of jaw ........ | 1·75 | |

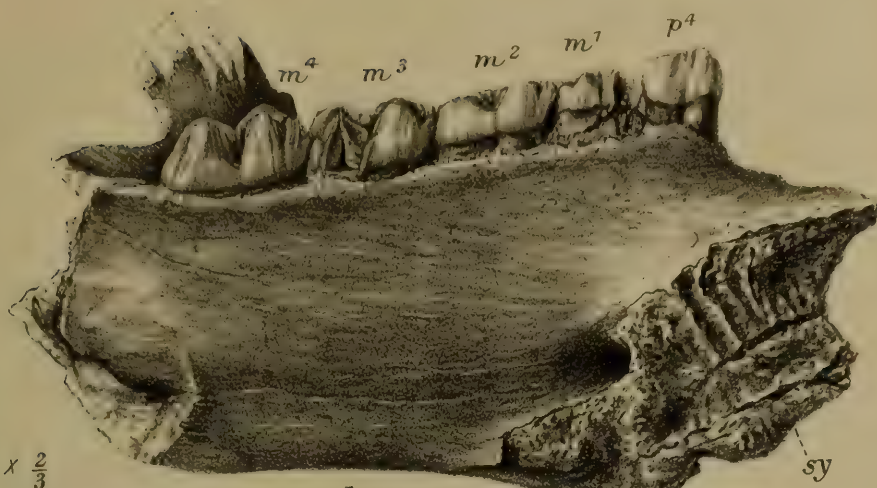
It may be added that the immature mandibular ramus figured in the Phil. Trans. for 1874, pl. lxxx. fig. 7, and referred to *P. Goliah*, differs from the specimens described as *P. Rapha* by the greater antero-posterior length of the fourth premolar, which is seen *in alveolo*.

The foregoing description leaves therefore no doubt as to the existence of two large-sized species of *Procoptodon* in the Australian Pleistocene, which are markedly distinguished from one another by the characters of their lower jaws. Both species were subject to considerable variations in size, which may have been either sexual or racial. Since the stouter and deeper type of jaw has been referred to the species described as *P. Rapha*, while one mandible of the more slender type has been described as *P. Goliah*, it seems advisable to allow these two types of mandible to be so named, until we obtain decisive evidence as to which really belongs to *P. Goliah*; if, indeed, the type of that species affords any characters by which it can be distinguished from the second species. The possibility that the types of those two species are really specifically identical must also be borne in mind; and if this should prove to be the case the name *P. pusio* might be the one which would have to be adopted for the second species. Here, however, the uncertainty again arises as to whether the type of that species indicates a small race of *P. Goliah* or of the second species.

## EXPLANATION OF PLATE XXI.

Fig. 1. Inner view of the left ramus of the mandible of *Procoptodon Rapha*.
2. Inner view of the right ramus of the mandible of *Procoptodon Goliah*.
2 *a*. Aperture of masseteric fossa of ditto.
2 *b*. Oral aspect of last two molars of ditto.
*an*. angle of mandible; *ca*. aperture of dental canal; *sy*. symphysis; *p*. 4, premolar; *m*. 1–4, molars.

With the exception of fig. 2 *b*, which is 1/1, the figures are 2/3 nat. size.




1


2 b.

2 a.


2.


R. Mintern del. et lith.

Mintern Bros. imp.

JAWS OF PROCOPTODON.

# 33. *On some* Recently-Exposed Sections *in the* Glacial Deposits *at* Hendon. By Henry Hicks, M.D., F.R.S., Sec. Geol. Soc. (Read May 27, 1891.)

[Plate XXII.]

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## I. Introduction.

For the past twenty years I have watched with interest the numerous exposures which have been made in the Glacial deposits at Hendon and in the adjoining areas, in making foundations for buildings, in digging for gravel, and in excavations in the course of laying down sewers. Some of the observations which I have made have been incorporated in the writings of authors who have referred to this area*, but hitherto I have avoided publishing the general results owing to the fact that new exposures which added fresh information were constantly being made. The recent completion of the main sewering of most of the parish of Hendon, however, has furnished data for giving a fairly complete summary which I now place before the Society. Twenty years ago the nature, extent, and boundary of these deposits were very imperfectly known, and doubt existed as to how they should be classified. When Mr. Henry Walker was making his researches in the Glacial deposits at Finchley, the results of which he communicated to the Geologists' Association in 1871, I expressed to him the opinion, which he mentions in his paper, that the sands and gravels at and near Hendon ought to be classed with the so-called Middle Sands and Gravels of the Eastern Counties. This view, which I still hold, is now generally adopted; but the clay-with-flints which overlies these beds on the Hendon Plateau has only recently been satisfactorily demonstrated to be, in part, the equivalent of the Chalky Boulder-clay at Finchley, Whetstone, &c.

## II. Some Recently-Exposed Sections.

When the sewer was being carried through Parson Street, directly opposite the Vicarage, 268 feet above Ordnance datum, a considerable thickness of Boulder-clay, resting on sand and gravel, was exposed in the excavation. It was of a bluish-grey colour,

* H. Walker, Proc. Geologists' Assoc. (1871) vol. ii. p. 288; Belt, Quarterly Journ. Sci. (1878); Whitaker, 'Geology of London' (1889).

and it contained, in addition to numerous unrolled white-coated flints, many distinct bits of chalk. Until recently this was the only perfectly satisfactory instance which had come under my observation in Hendon of a typical chalky Boulder-clay similar to that which is so well known at Finchley.

That the Upper Boulder-clay must have been spread out very generally over the Hendon plateau, and by the same agency as that which deposited it on the areas farther north, is now certain. What is here mostly found, however, is a brown or yellowish-brown clay like that which at Whetstone and Finchley usually occurs below, but also frequently passes into and occupies the position of the more distinctly chalky clay. In some places it is very stony, but more often the fragments and pebbles are only scattered about in it. In parts also there is an almost entire absence of pebbles and rock-fragments.

In a drain recently made in the Green Lane on the Hendon slope, looking towards the Brent Valley, and 175 feet only above Ordnance datum-line, a brown clay was exposed which yielded many fragments of a hard white chalk, the largest piece being about 2 inches long. The clay was also seamed in all directions with decomposing carbonate of lime ("race"). The occurrence of this Chalky Boulder-clay at so low an horizon is interesting also as proving conclusively that the Brent Valley had been in the main scooped out previous to the deposition in it of the newer Glacial deposits. Moreover, on the Finchley side of the valley there is equally good evidence, for the Boulder-clay is found there also at many points considerably below the 200-feet contour-line.

In an extensive pit, opened in the year 1889, near the centre of the plateau upon which Hendon is situated, and about $\frac{1}{2}$ mile S.E. of the exposure referred to in Parson Street, an average thickness of 7 feet of a brown clay with bluish streaks was exposed, resting upon about 8 feet of sand and gravel. This pit is about 245 feet above Ordnance-datum, and has been dug in a field opposite West View, between New Brent Street and Heriot Road. When the underlying floor of London Clay was reached it was found to be very irregular in character, and resting on this floor were large masses of angular sarsen-stones, in some cases showing what appeared to be distinct traces of ice-markings. As the pit was enlarged, it was seen that the Upper Boulder-clay sometimes reached downwards through the Sands and Gravels until it had completely penetrated them and touched the underlying floor of London Clay. In a deep drain which was carried from this pit in a S.W. direction for about 130 yards for the purpose of drawing off the water, several of these channels filled with Boulder-clay were met with, the Sands and Gravels lying between in a comparatively undisturbed condition. These channels varied from a few feet to several yards in width. In the pit and drain the floor of London Clay was found to be very uneven, rising up here and there in hillocks, and as the Gravels were seen to pass horizontally across these banks, it became evident that such irregularities must

have been produced by ice-action prior to the deposition of the Gravels in them. At the eastern end of the pit the Upper Boulder-clay, like that mentioned as occurring in the Green Lane and 70 feet lower, contains many decomposed patches and concretions of carbonate of lime resembling the "race" found in some brick-earths. Here the "race" occurs most abundantly near the base of the clay. Mr. Whitaker, in describing the Glacial deposits at Church End, Finchley*, refers also to the fact that the brown clay there found underlying the Chalky Boulder-clay contains much "race." The resemblance between this brown clay, when, as is often the case, it contains scarcely any pebbles, and the London Clay is particularly striking, and leads one to the conclusion that much of the brown clay must have been derived by denudation from exposed surfaces of London Clay during the Glacial period†.

There are several patches of sandy gravel enclosed in the Upper Clay in this pit which, it is clear, must have been torn off as frozen masses from underlying beds and re-deposited as boulders in the clay. The sandy gravel in these patches oftens exhibits a rough oblique stratification, and the materials seem to be identical with those in the underlying gravels here and elsewhere in the neighbourhood. Over the surface of the clay, and filling some depressions in it, a rough gravel is frequently found, the result probably of the subsequent denudation of the Boulder-clay by sub-aerial action and flood-waters at the close of the Glacial period. This gravel has been spread out very generally as a thin coating over the neighbourhood, and extends beyond the line on the Map, which is intended to indicate the boundary of the more typical Glacial deposits.

As this gravel contains many white-coated fresh-looking flints and subangular fragments and some northern erratics in association with the well-rolled pebbles from the Tertiary beds, it is evident that it must have been derived immediately from a Boulder-clay which had been spread out very universally over the area, especially as it is now found not only on most of the hills and slopes east and west of the Hendon plateau, but also between it and the Thames Valley.

In the section (fig. 1, see next page) which was recently exposed at the S.E. corner of the pit A, the rough gravel at the base contained many angular masses of sarsen-stones and large flint blocks, some of the latter being but little worn and having white-coated surfaces. The majority of the flints, however, here as elsewhere, are well-rolled pebbles, and must have been derived by denudation from Eocene beds in the neighbourhood. There were also numerous fragments of chert and ferruginous sandstone, evidently derived from the Lower Greensand, and also some pebbles of quartz, quartzite, ironstone, &c. In this pit the lower rough gravels vary in thickness from 2 to 4 feet, according to the irregularity of the floor. Between the sandy gravels

* 'Geology of London' (1889), vol. i. p. 311.

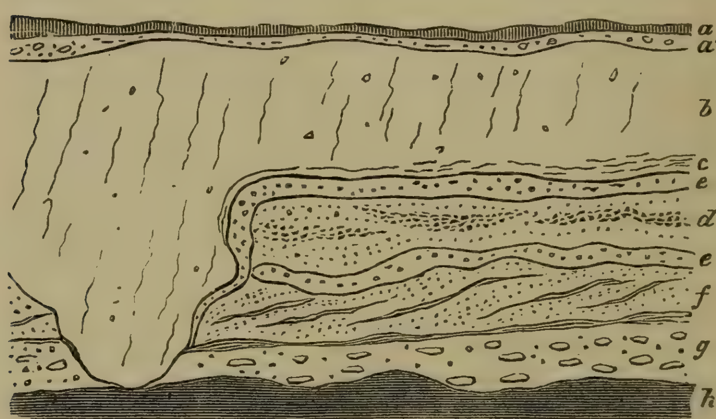
† Mr. H. B. Woodward refers also to this resemblance, and says that this clay is "often very like London Clay," *op. cit.* vol. i. p. 309.

Fig. 1.—*Section in West View Gravel-pit.*

[About 20 feet in length.]


*a.* Surface soil.
*a'.* Gravelly soil.
*b.* Brown clay, with a few flints, patches of gravel, and in places much 'rače.'
*c.* Laminated sandy clay.
*d.* Grey sandy gravel.
*f.* Yellowish sand with seams of clay.
*g.* Gravel with angular masses of sarsen-stone, subangular flints and flint-pebbles, chert, quartzite, &c.
*h.* London Clay.

Fig. 2.—*Section on the W. Side of West View Gravel-pit.*




*a.* Surface soil.
*a'.* Gravelly soil with white-coated flints, &c. } Irregular.
*b.* Brown clay, with blue streaks and with a few flint-pebbles (6–15 feet).
*c.* Laminated sandy clay (6 inches).
*d.* Ochreous sandy gravel.
*e.* Bands of grey subangular gravel. } 5 feet.
*f.* Ochreous sand with seams of clay.
*g.* Coarse gravel (2–4 feet).
*h.* London Clay.

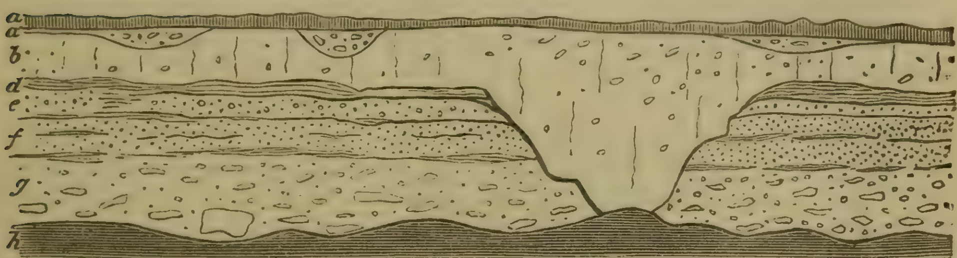
and the Boulder-clay there is usually from 6 to 12 inches of a sandy laminated clay, almost entirely devoid of stones*.

In one part of the pit the laminated clay and an underlying band of gravel were seen to have been bent down into one of the channels in a rather remarkable manner (fig. 2); and as there is no indication of a sinking of the surface, or of any increased thickness of soil over the Boulder-clay, it seems evident that this effect must have been produced contemporaneously and mainly by pressure, when the overlying Boulder-clay was deposited, especially as the other beds which underlie the laminated clay are also in a disturbed and contorted condition.

Section 3, which has been exposed during the last two years in a field at Hendon Grove near the western edge of the plateau,

Fig. 3.—*Section in Upper Gravel-pit, at Hendon Grove.*

[About 35 feet in length.]




*a.* Surface soil.
*a'.* Gravelly soil (with flints). Irregular.
*b.* Yellowish-brown clay, in places passing downwards through the underlying sands and gravels (2–7 feet).
*d.* Loamy sand with ochreous bands (1 foot).
*e.* Gravel (1 foot).
*f.* Yellowish sand, sometimes showing current-bedding (2 feet).
*g.* Ochreous gravel, with large pieces of sarsen-stone, rounded and subangular flints, chert, quartzite, quartz, ironstone, &c. (2–4 feet).
*h.* London Clay, much disturbed, of a brown colour, and forming a very uneven floor under the Glacial deposits.

offers evidence very similar to that referred to as occurring in the West View pit, the chief difference being a diminished thickness of Upper Boulder-clay. Within a very short distance, however, from this point, in the excavation made in laying down the sewer in the road leading to St. Mary's Church, about 285 feet above O. D., from six to eight feet of clay were passed through before the sand was reached. The London Clay was touched at from 14 to 16 feet from the surface. It must be understood that, in the scores of sections exposed in pits and deep drains at various points, considerable variability has been frequently observed in all the deposits.

* A similar laminated clay has been mentioned by Mr. H. B. Woodward as occurring frequently under the Chalky Boulder-clay, and I have also recently seen it occupying the same position in a large gravel-pit at Whetstone and in pits at Finchley, &c.

In some cases there was an almost complete absence of gravel and a preponderance of fine sand, whilst in others the whole thickness was found to consist of a sandy gravel. Everywhere, however, except where the furrows containing the overlying Boulder-clay reach downwards to the London Clay, some amount of sand or gravel is present under the clay, usually in a stratified condition, and showing well-marked lines of current-bedding. When there were but few pits opened, and no continuous sections had been seen, I was led, on one or two occasions, to form a mistaken idea as to the thickness of the Glacial deposits in some parts of the district, by calculating, from some excavations which happened to have been made in one of the channels containing Boulder-clay (without reaching gravel at the base), that an average thickness of the sands probably occurred below. From the excavations which have been made since then for the sewers, and other more continuous sections, I have obtained sufficient evidence to show that, where well-sinkings had exposed an unusual thickness (*i. e.* 15 or more feet) of the Boulder-clay, they had been sunk in the depressed masses, and there was but little, if any, gravel separating it there from the London Clay. As demonstrating the practical utility of some acquaintance with the physical conditions under which these deposits were accumulated, I may mention that in this district, where sand and gravel command a very high price for building purposes and laying out of paths, the search for gravel has often been discarded, because it was not known that over most of the plateau there was a considerable thickness of clay overlying the sand, and where test-holes had been made they had frequently either not been carried deep enough, or had pierced one of these channels filled up by the Upper Boulder-clay. From finding a certain amount of washed gravel on the surface of the clay, it had also frequently been supposed that it occurred only in pockets in the clay, whilst a further boring of two or three feet would often have revealed the presence below of 7 or 8 feet of good sand and gravel, equal, if not superior, to that which for building purposes would have to be carted from the Thames Valley or brought from Hertfordshire or Bedfordshire. On several occasions also I noticed that where the lower gravels had been removed all further search had been suddenly abandoned, in consequence of meeting with a depressed mass of Upper Clay, whilst had the mass been crossed the gravels would have been again reached within a few yards. The largest gravel-pit at present in the neighbourhood, the one from which fig. 1 is taken, was opened at my suggestion by the men who had been digging gravel for my own use in my grounds, and it was with difficulty that I could persuade them that the gravel would be reached below the 7 or 8 feet of the stiff brown clay which is found in that pit.

As showing how the previously-formed hills of London Clay have been, as it were, mantled by the Glacial deposits, the sections at Hendon Grove are particularly instructive. At the highest point on the edge of the plateau, about 280 feet above Ordnance datum,

an excavation extending to over 60 feet has been made, exhibiting the conditions witnessed in fig. 3. Towards the north end of the pit B, the floor was seen to rise up rather suddenly, and the sand and gravels diminished to a few feet. Towards the south end a mass of Boulder-clay, about 12 feet across, dipped down suddenly till it rested on the underlying London Clay without the intervention of any sand or gravel. Between these points there was an average thickness of 6 to 7 feet of more or less well-stratified sand and gravel, and at the base, resting on the London Clay, were several masses of sarsen-stone, 2 to $2\frac{1}{2}$ feet in length. The lower gravel also contained, scattered about in it, several large angular masses of sarsen-stone, large but slightly-worn flints, and sometimes masses of a brown-clay much resembling the underlying London Clay. On the westward slope, at a distance of about 150 feet from this pit, and some 25 feet lower in horizon, another pit (C) was opened. Here it was found that the lower rough gravels, which averaged about 4 feet in the upper pit, were greatly diminished in thickness, and were replaced by clean white sand, the beds above being on the whole almost identical with those in the upper pit. A wide depressed mass of the Upper Boulder-clay was also found to come in at the south side of this pit. In some deep drains, which were made for the purpose of carrying away the water from these pits, similar varying conditions were witnessed *. It will be seen, therefore, that these Glacial deposits do not, as has been usually supposed, merely rest on a plateau of the London Clay, but they lie on a very irregular surface and descend everywhere along slopes of previously formed depressions and valleys in the London Clay. I have carefully traced the sections along the slopes, and I find that there is sometimes a difference of at least a hundred feet from the highest point at which London Clay has been touched on the ridge, to that in which it is found underlying almost identical sections on the slopes.

### III. Distribution of the Glacial Deposits.

On the accompanying map (Pl. XXII.) I have outlined the margin of the deposits, so far as they have been made clear through pits and in sewering the district, and I have indicated some of the spots where the deposits have been well exposed. It will be observed that the patch occupies an area more than three times the size of that shown in the Geological-Survey map of surface deposits. Many years ago I mentioned to Mr. Whitaker and to Mr. Horace B. Woodward that the deposits extended beyond the limit shown, and in the recent excellent Memoir of the Geological Survey they have fully referred to the facts I then communicated to them. Much additional evidence has, however, been since obtained, and the boundary has been further extended. The nature and contents of

* A test-hole was recently dug at the bottom of this field, about 65 feet below the horizon of the upper pit, and similar sand and gravel was met with. covered by about 3 feet of Boulder-clay. Here more 'race' was found in the clay than in the excavations higher up in the field.

the deposits also have been far more completely made out in the more recent exposures referred to in this paper.

In the patch directly north of the Hendon plateau, upon which no pits are indicated, so few exposures have been made that the boundaries of the Glacial Drift can only be approximately given, and the evidence of its character has been derived mainly from shallow drains at various points, and from the railway-cutting and some deep wells in Page Street, just beyond the limit of the Map accompanying the present paper (Pl. XXII.). What has been exposed in the shallow drains was mainly a yellowish-brown clay containing many flint-pebbles, but some gravel was met with in the railway-cutting, and it must also be present where the wells have been sunk. That at the Tithe Farm is stated to be about 20 feet deep.

In the two other patches along the W. side of the Brent Valley the deposits have been exposed in gravel-pits and deep wells and in excavations for the main sewer. At Holder's Hill the Boulder-clay was found to attain to a considerable thickness, and it resembled that found on the Hendon plateau. The area on the Finchley side of the Brent (indicated as covered with Glacial deposits) contains in places the typical Chalky Boulder-clay, but at most points along the sides of the Brent Valley a thick coating of brown clay overlies the sands and gravels. In the patches at Temple Fortune and Golder's Green the clay is also mainly of a brown or yellowish-brown colour, and no typical Chalky Clay has hitherto been discovered there. Sands and gravels were exposed at several points in the sewer excavations in these areas, and much sand and gravel was obtained some years ago in a field on the south side of Bridge Lane, between the Decoy Farm and Temple Fortune. The Golder's Green patch might well be extended to the west side of Hampstead Hill, for Glacial deposits have been exposed at several points between the Brent Valley and the slope of that hill.

## IV. Conclusions.

There can now be no doubt that Glacial deposits similar to those found at Finchley and Whetstone on the N.E. were spread out in a S.W. direction across the Brent Valley and over the Hendon plateau, reaching downwards on the slopes to below the Ordnance datum-line of 200 feet. There is good evidence also to show that they passed across the valley separating Hendon from Kingsbury, and that they now occur on most of the heights in the latter parish. They are also found at Dollis Hill, and at some other points in the parish of Willesden. It is certain, therefore, that the physical features of this part of N.W. Middlesex were moulded at a very early stage in the Glacial period, or clearly previous to the deposition of the so-called Middle Sands and Gravels, and of the Upper or Chalky Boulder-clay. At this time there could have been no barrier of any importance to prevent these deposits from extending into the Thames Valley, and the evidence clearly points to the conclusion that the implement-bearing deposits on the higher horizons in the Thames Valley should be classed as of contempo-

raneous age with these undoubted Glacial deposits at Hendon and Finchley, which they so closely resemble. This necessarily indicates that man lived in the neighbourhood of the Thames Valley at least during a portion of the Glacial period, if not, as is highly probable, in pre-Glacial times.

PLATE XXII.

Map showing the Distribution of the Glacial Deposits in and around Hendon.

## Discussion.

Mr. H. B. Woodward said the chief interest of the sections related to the brown clay that occurred between the two layers of gravel. When he surveyed the Hendon outlier (in 1869) the lower gravel was not exposed, and he took the brown clay to be London Clay. Dr. Hicks had clearly proved that this brown clay belonged to the Glacial Drift. It could hardly be regarded as true Boulder-clay, for although patches of gravel had been caught up in it, there were no true erratic boulders, so far as he was aware, and the "scratched stones" mentioned by Dr. Hicks afforded no convincing evidence of glacial striæ. The brown clay, however, behaved much like Boulder-clay in the way in which it had here and there cut abruptly into the beds below, and it might be regarded as a reconstructed mass, a kind of boulder, in fact, of London Clay. The "race" was a secondary product, due perhaps to the decomposition of fragments of septaria derived from the London Clay.

The features of the district, as Dr. Hicks maintained, were to a large extent of pre-Glacial origin. He had come to this conclusion while at work in Essex, where, as near Brentwood, the Glacial Drifts smothered up some of the old features and abutted against pre-existing outliers of Bagshot Beds.

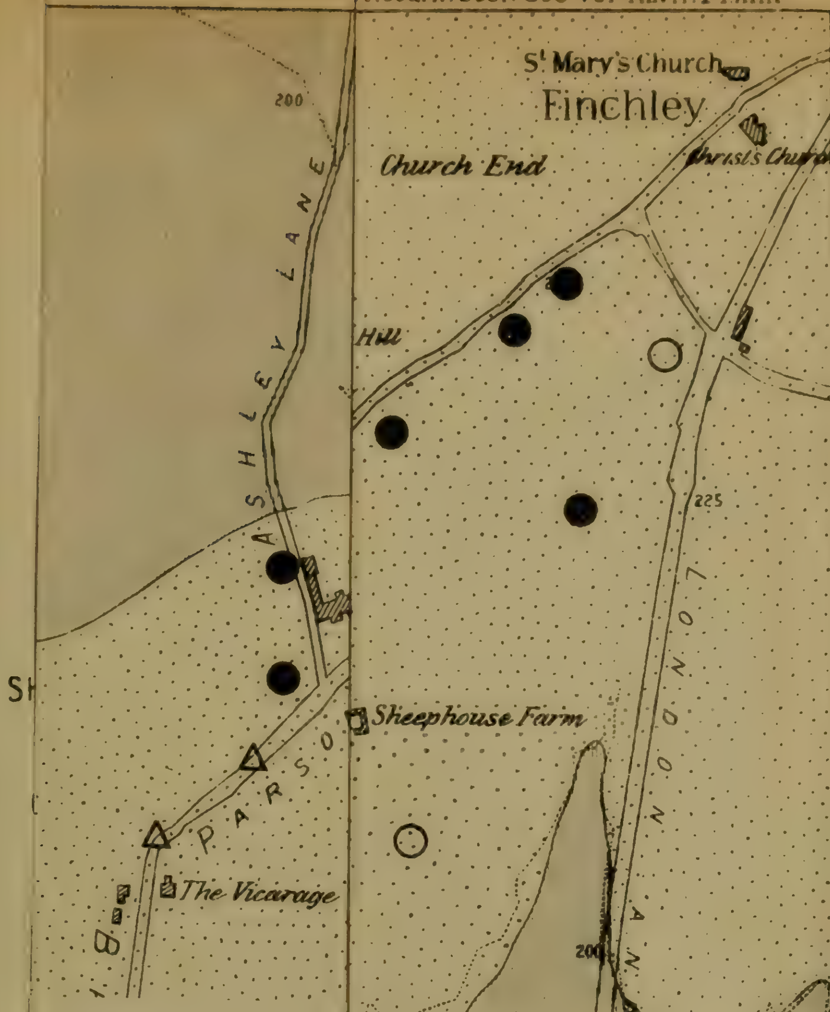
Mr. J. Allen Brown regarded the paper as of much importance to those who, like himself, had been engaged in the investigation of the Quaternary deposits in Middlesex. He pointed out the similarity in many respects between the sections now shown and those at "The Mount," Ealing, described and figured by him in the Proceedings of the Geologists' Association. In an excavation made lately on Castlebar Hill, Ealing, of which he had made sections, as yet unpublished, there was the same abrupt cutting off of the gravel beds as shown in one of the present sections and the like infilling of brown (probably) Boulder-clay; he considered that such brown redeposited London Clay was the equivalent of Boulder-clay, although the boulders and chalky material were often absent. The matter left by ice traversing a clayey country would necessarily be chiefly composed of clay, and what chalk might have been originally in it would probably be dissolved out or redeposited as "race." There was more chalky matter in such deposits the nearer the Boulder-clay was found to the outcrop of the Chalk. He had seen chalk, sometimes in large masses, with the stratified implementiferous gravels bent and contorted between them, in the high-level drift-gravel near Langley (Bucks), showing the passage of very large masses of ice during the period when man was existing there.

He desired to know whether the Author had analysed the gravel seen in these sections and whether he could distinguish any difference between the constituents of the higher bed and that at the base, and what proportion of Southern Drift he found there, this being a matter of considerable importance, now that Professor Prestwich's valuable series of papers had appeared. With regard to the analogous deposit on Castlebar Hill, Ealing (about 160 O.D.), he had found in it about 8 per cent. of ragstone and chert pebbles; 7 per cent. of white quartz, of which the largest was but little bigger than a pea; no northern rock but a small pebble of light quartzite; about 12 per cent. of black Tertiary pebbles, and the rest flint-pebbles and subangular pieces of flint more or less stained, with some blocks of sarsen-stone much eroded.

Dr. G. J. Hinde called attention to the fact that a notable proportion of the fragments from the Hendon Beds, exhibited by the Author, consists of cherty rock, similar to that forming the Sponge-beds of the Lower Greensand in Kent and Surrey, from 20 to 30 miles to the *south* of London; and the mode of their occurrence in their present position had not yet been explained.

Mr. Monckton remarked that the Glacial Gravels were very largely composed of material derived from the near neighbourhood, and this favoured the view that the valleys in which the gravels are found were not previously formed, but were contemporaneous with the formation of the gravels: that is, the portion of the valley in which the gravels occur. In reference to Prof. Prestwich's suggestion (Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 136) that the Hendon Gravels might be Westleton, he considered that the presence of a large proportion of subangular flints and the absence of any great quantity of quartz-pebbles showed they were not Westleton but Glacial gravels. He did not think that they were Southern Drift.

The Author, in reply to Mr. Woodward, said he did not refer to the seams of clay as having been torn off from the floor by ice, but to some distinct masses which were found enclosed in the Lower Gravels. Replying to Mr. Monckton, he stated that when he said that there was no barrier of any importance between Hendon and the Thames Valley, he meant no continuous hills like those of Hampstead and Highgate. The Brent Valley, which undoubtedly had been scooped out before the Upper Boulder-clay was deposited over the district, especially offered every facility for the extension of the material in that direction. It was interesting to know that Mr. Monckton and Dr. Hinde recognized a similarity between the chert fragments and the chert of the Lower Greensand in the south; but he thought it probable that similar beds must have been exposed somewhere to the north, as about an equal proportion occurred in the gravels underlying the Chalky Boulder-clay as far north as Whetstone. The Author was very glad to find that Mr. Allen Brown had obtained further evidence to show that Glacial deposits occurred near Ealing, and he had no doubt that ere long it would be possible to show that they extended almost continuously from Hendon to that area.


St Mary's Church
Finchley
Church End
Christ's Church
ASHLEY LANE
Hill
225
200
Sheephouse Farm
PARSO
The Vicarage
SH

# MAP
## SHOWING THE DISTRIBUTION OF THE GLACIAL DEPOSITS IN HENDON AND THE ADJOINING AREAS

*Scale six inches to one Mile*

## INDEX.

- *Glacial Deposits consisting of Boulder-Clay, sand and gravel.*
- *London-Clay covered in places by gravelly soil, rain and river wash.*
- △ *Positions of Sewers and drains, where the Glacial Deposits have been exposed.*
- ○ *Positions of open Sections* } *Wells & pits where the Glacial Deposits have been exposed.*
- ● *Positions of closed Sections* }
- A *West View Pit, (Sections 1 & 2.)*
- B *Upper Pit Hendon Grove (Section 3.)*
- C *Lower Pit, Hendon Grove.*
- ..... *200 ft Contour-line*
- ____ *Geological boundaries.*

## 34. *On* Wells *in* West Suffolk Boulder-clay. By the Rev. Edwin Hill, M.A., F.G.S. (Read June 24, 1891.)

On taking up my residence in the heart of the Suffolk Boulder-clay, I at once began to enquire the depths of wells, in order to learn the thickness of its mass. The nature of the answers was unexpected. The depths at which water is obtained appeared altogether irregular and capricious; ultimately it seemed necessary to conclude that in some cases, possibly in many, the water is met with not below but in the interior of the Clay itself.

Here is an instance. A well in an outhouse of this Rectory (Cockfield, seven miles S.S.E. of Bury St. Edmund's) gives water at a depth of 35 feet. Another, outside its grounds, 120 yards W., is 74 feet deep, and I am told that in sinking it no water was obtained till this depth was reached. But another, the same distance N.N.W. of the first, is only some 8 or 10 feet in depth. Boulder-clay forms the subsoil to within a few inches of the surface, which in the case of each of these wells is about 300 feet above Ordnance datum.

Other wells have the following depths, the distances and directions being measured from the Rectory:—One half a mile N.N.E. (surface about 290 feet) * 50 feet; another a quarter of a mile N. (300 feet) 70 feet. In the opposite direction, at Cockfield New Hall, three quarters of a mile S.W. (255 feet), water was found at various depths down to 35 feet, but at the New Barn, a quarter of a mile farther S.W. (about 280 feet), the depth was 126 feet. At the Post Office, about a mile W.N.W. of the Rectory (about 270 feet), a shaft was sunk 83 feet and abandoned, nothing beyond surface-water having been obtained, while a few hundred yards off in several directions supplies are furnished by wells of varying but moderate depths.

It may be asked whether these irregular depths may not be due to the irregular surface upon which the Clay is lying. But the water-levels in the three wells first named, so near, yet of such different depths, appear to have no connexion. Again, such an irregular subsurface must certainly be intersected by any long trench if of any serious depth. Such a trench exists in the valley of a brook which runs from N. to S., passing about half a mile west of the Rectory, and more than 70 feet below the levels there. This valley taps a few springs, and here and there in the bed of the brook a little gravel may be seen. But nowhere do I see any indication that it has reached an extensive underlying formation. The conclusion I come to is, that the water must be contained in permeable seams, included in the mass of the Boulder-clay.

The Clay itself appears absolutely impervious to moisture. In a neighbouring field water stood for several weeks in a small pit by the side of a deeper trench not two feet off. A shallow ditch recently dug along a fence a few inches into the Clay lay

* Numbers between parentheses indicate height of *surface* above sea-level.

perfectly dry until a fall of snow. When this melted and filled it, the water stood there day after day till it disappeared by evaporation. But then, this clay being thus impervious, the question arises, how does the rainfall find its way down to the water-bearing seams? In the Geol. Surv. Mem. on quarter-sheet 51 S.E. (1886), which includes the west boundary of this parish *, it is said that "owing to the boulders and stones it [the clay] contains, and also to occasional seams of sand, wells are often made in it and a fair supply of water obtained." But the boulders and stones do not make it pervious: yet these sand-seams must obtain their water from the surface. I conclude then that this Boulder-clay is not an uniform homogeneous mass; it must contain seams or beds of gravel and sand, and these must rise to the surface, or in some way communicate with it.

This conclusion was altogether contrary to my preconceived ideas. I knew that many geologists regarded this Boulder-clay as formed beneath a glacier by the friction of a mass forced forward over its bed. I expected therefore to find a clay perfectly impervious to water, and with any appearance of bedding which it might present parallel to the direction of motion. I have looked attentively at all visible sections. Those in the immediate neighbourhood are only such as ditches can give. They showed pockets and patches containing sand or silt of irregular and fantastic shapes, and though, by reason of denudation, it is probable that this is no superficial structure, they are necessarily very limited and unsatisfactory. As yet I have been able to examine more extensive sections only in two localities, namely, Bury St. Edmund's, seven miles to the N.N.W., and Sudbury, ten miles to the S. Near Bury, just beyond Horringer (Horningsheath) Red House, a large pit in the fields shows about 8 feet of Boulder-clay resting on gravel, and below the gravel, chalk. Here then we have the base of the Clay shown for several hundred yards. It is typical Boulder-clay of a reddish colour, full of chalk and flints. But in the middle, at my first visit in Nov. 1890, was a mass about 12 yards long clearly distinguished by its bluish tint from the rest; on one side it abutted against this vertically, on the other overlay it obliquely. At Sudbury Boulder-clay is seen in several pits, one of which contains the remarkable mass described by Mr. Marr in the Geol. Mag. for 1887 (p. 262). The best section is that in the Ballingdon Brick-yards, across the river, about half a mile N.W. of the Sudbury Railway Station. Here, below the thin surface-soil, is some 10 feet of yellow Boulder-clay, in which a sandy streak, visible at some distance, runs for several feet horizontally, then turns up and bends back till it reaches the surface. Below the clay is from 12 to 20 feet of much contorted stratified gravel. This lies on the irregular surface of a second Boulder-clay, very dark in its upper portion, but light with dark patches below, and containing irregular patches and seams of yellow sandy clay. About 20 feet of this lower mass was

* Cockfield is mainly included in quarter-sheet 50, S.W. The memoir on this map was published in 1881.

seen, but not what it rested on, except that at one spot the workmen had struck an excessively hard gritty bed, apparently cemented by carbonate of lime. Both upper and lower clay were well shown by freshly cut faces, and both were by no means homogeneous masses.

The appearances both at Bury St. Edmund's and at Sudbury are quite different from what I should expect in a mass resulting from the abrasion by a glacier of its bed. As no one (so far as I know) has ever seen a so-called "ground-moraine" beneath an existing glacier, we can only argue by analogy. According to the supposed method of formation I should expect this to possess a structure analogous to that produced when a sledge is dragged over soil. No section shows such appearances.

I think it worth while to call attention to these facts, as a satisfactory theory of the origin of this vast mass must give a satisfactory account of its phenomena. I have no theory of my own at present to propound, but I hope to continue observations on this interesting and difficult subject.

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### *Note on the Cockfield Post-Office Well.*

*Locality.*—Cockfield Post Office, rather more than half a mile N.W. of Cockfield Railway Station. Height above O.D. about 270 feet. The bed of the brook is about a quarter of a mile east, less than 40 feet below.

| | feet. |
|---|---|
| (1) Yellow clay (Brick earth?) ........................................ about | 8 |
| (2) Red gravel with large flints ........................................ | 7 |
| (3) Yellow clay with much small chalk ........................................ | 3 |
| (4) Blue Boulder-clay with much chalk in well-rounded pebbles... | 40 |
| (5) Broken lumps of chalk and flints ........................................ | 5 |
| (6) Blue clay with sub-rounded chalk fragments, base not reached. | |

The well was continued in (6) to a total depth of 83 feet, and then abandoned, no water having been met with below the gravel.

In (4) were masses of dark calcareous clay, full of ammonites, &c. (Kimmeridge Clay?), often scratched. At the depth of 22 feet a chalk boulder at least two feet long was met with. When (5) was reached it was at first supposed to be the surface of the Chalk itself. In (6) the chalk fragments were mostly as large as pigeons' eggs; flints were certainly less numerous than in (4), both according to my own observation and the opinion of the well-sinker. The well was begun in March 1890, and abandoned in May of the same year.

### Discussion.

Prof. Prestwich remarked that intercalated beds of gravel and sand were common at different levels in the more northern Boulder-clay, and that in parts of the Eastern Counties a bed of gravel, from 1 to 20 feet thick, generally occurred in the centre of the Boulder-clay. These formed small water-bearing beds, but the

main sources were usually at the base of the Clay—a base which was extremely irregular. He asked the Author how, as the wells stopped at the water-bearing stratum, he could be sure that this was, in all instances, intercalated and not an underlying bed. It was essential to know the level of the ground at the different wells, and this would no doubt be given in the paper. The component beds of the Boulder-clay would vary according to the surface passed over by the ice, and may, therefore, include long trails of sands and gravels, and are necessarily local and irregular. He hoped that the Author would continue his observations.

Dr. Evans agreed with the Author in regarding the mixed character of the Boulder-clay of Suffolk and some of the features that it presents as being hardly consistent with its being merely the result of a coating of land-ice. In illustration of the permeability of the beds at certain spots, he cited the deep circular pits or meres in the neighbourhood of East Wretham, Thetford, which were due to the dissolution of the underlying Chalk by water charged with carbonic acid having forced its way through the Clay. The level of the water in these meres depends upon the saturation of the Chalk, and the bottom of what in one year was a deep pool might in another year be cropped with turnips.

Mr. Clement Reid observed that intercalations of seams of sand were almost universally characteristic of the Boulder-clay, and helped to render it somewhat pervious to water. He was unable to follow the Author's argument, that irregularities in the deposits proved that the Boulder-clay could not have been formed under ice.

Mr. Charlesworth said that at Saffron Walden in Essex, on the borders of West Suffolk, the Boulder-clay is now being quarried on an extensive scale for the purpose of making in combination with Chalk what is there called "Portland cement." The denudation of the Chalk and Oxford Clay has largely contributed to this Boulder-clay at Saffron Walden; and sections of the deposit are displayed of extreme geological interest.

Mr. Topley called attention to the researches upon the glacial geology of the Eden Valley carried on by Mr. Goodchild, who believed (as does Mr. Reid for Norfolk) that the irregular beds of gravel and sand occurring in the Clay were formed within or under the ice-sheet, the gravel, &c., having been washed out of the Clay into hollows of the ice during partial or local melting of the ice-sheet.

Mr. Goodchild said that similar intercalations of sands and gravels in the Boulder-clay were common in the North. He reminded the Society that he had proposed an explanation of the origin of such deposits many years ago in the Society's Journal and elsewhere (Quart. Journ. Geol. Soc. vol. xxxi. (1875), and Geol. Mag. for 1874).

The President referred to his own early work in the Boulder-clay and the abundant evidence which he had everywhere found of intercalated nests and layers of sand and gravel in that deposit. He had always been accustomed to regard these intercalations and

their singular contortions as affording some of the strongest proofs of glacier-action, and though he admitted that the Boulder-clay still presented many unsolved difficulties, he had never seen what he could regard as a valid argument against the view that the true typical Boulder-clay is essentially a product of land-ice.

The Author, in answer to Prof. Prestwich, said that he had taken into account the variations in surface-level of spots where wells existed. Dr. Evans's instances of permeability in Boulder-clay were a valuable corroboration. The appearances of sections did not to himself suggest an origin such as erosion by subglacial streams. He would be very glad to study the sections at Saffron Walden and those in the Eden Valley described by Mr. Goodchild. He was not aware of any case in which a "ground-moraine" had been seen in actual process of formation, but he imagined that any structures possessed by a mass so formed would be horizontal in their general direction. The appearances described in the paper were not of that character.

# 35. Notes *on the* Geology *of the* Tonga Islands. By J. J. Lister, Esq., M.A. (Read June 24, 1891.)

[Communicated by J. E. Marr, Esq., M.A., F.R.S., Sec. G.S.]

[Plate XXIII.]

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## I. Introduction.

Very little of a detailed character has, so far as I am aware, been published on the geology of the Tonga Islands.

Prof. Dana makes a brief mention of some of the islands in 'Coral and Coral Islands' *; and in the edition of 'Coral Reefs' published in 1874 Darwin gave a summary of what was known of the group †.

I spent several months in Tonga in 1889 and 1890, and had opportunities of visiting some of the islands in H.M.S. 'Egeria,' which was engaged, for part of the time, in making a survey. Such observations as I made on the geology of the group are embodied in the following notes.

I am indebted to Mr. Alfred Harker, M.A., F.G.S., who has examined the volcanic rocks which I obtained ‡, and also to Dr. John Murray, who has looked over sections of the calcareous rocks of Eua.

## II. Topography of the Group.

The Tonga or Friendly Islands are situated in the Pacific Ocean between 18° and 22° 30′ lat. S., and on either side of the 175th degree long. W. Tongatabu lies a little over 1000 miles to the N.N.E. of Auckland in New Zealand. The large islands of Fiji are about 400 miles to the W.N.W., and those of Samoa about 300 miles to the N.N.E.

The greater number of islands fall into three main groups. The northernmost is Vavau, which consists of one moderately large island (about 13 miles in its longest diameter), giving its name to

* 2nd ed., pp. 288 & 289.

† P. 212 and elsewhere, 3rd ed. (1889).

‡ Mr. Harker has published notes on these specimens in the Geol. Mag. for June, 1891.

the group, and a number of islets lying to the south and south-west of it. Rather more than fifty miles to the south is the Hapai group, containing the high volcanic islands of Tofua and Kao on the west; on the east a chain of low, flat, coral islets; the Kotu group in the centre; and on the south a number of isolated islands, the largest of which is Nomuka. Some fifty miles to the south and somewhat to the west of Nomuka lies Tongatabu, the largest island of the group, measuring over twenty miles in its longest diameter. A channel about ten miles broad separates Tongatabu from the small and high island of Eua to the south-east, while eighty-five miles to the south-west lies the little island called Ata by the natives, the Pylstaart of the charts, the most southerly outlier of the Tonga Islands. (See Map on p. 594 and Pl. XXIII.)

Lying far to the north of the islands mentioned are Niuafou (=Good Hope, or Proby Island), Keppel, and Boscawen Islands, which, though politically belonging to Tonga, occupy an intermediate position between this group, Fiji, and Samoa.

## III. Geological Characters of the Group.

According to the characters which they present, the Tonga Islands may be arranged in three divisions, viz.:—(*a*) purely volcanic islands; (*b*) islands formed of volcanic materials laid out beneath the sea, and since elevated, with or without a covering of reef-limestones; and (*c*) islands formed entirely of reef-limestones.

### (a) *The Volcanic Islands.*

The purely volcanic islands form a line running parallel to the long axis of the group, but a little to the west of it. The direction of this line is approximately N.N.E. and S.S.W.

At the southern end is the little island of Ata or Pylstaart, which, judging from the extremely steep and rugged outline that it presents, may possibly be a member of this series. I have, however, merely seen a photograph of the island, and it can therefore only provisionally be reckoned a member of the volcanic series.

The islands of Honga-tonga and Honga-hapai, lying north of the west end of Tongatabu, are I believe the fragments of an old crater. They stand out of the sea about a mile and a half apart, and reach a height of some 300 and 200 feet respectively. Each island has a high vertical face on the side turned towards the other, and on all sides hard black layers of rock are seen alternating with softer ones, and slope away from a point situated between the two islands.

Fifteen miles to the north of these islands is the recently-formed volcanic mound named Falcon Island.

In the year 1867, H.M.S. 'Falcon' reported a shoal in the position of the present island, and ten years later smoke was seen issuing from the sea at this spot by H.M.S. 'Sappho.' In October 1885, a submarine volcano suddenly burst into activity, and built up a

mound. The volcano was still in eruption the following year. In 1887 the height was estimated as 290 feet by a French man-of-war; and from a sketch taken in that year, it appears that the summit of the island presented a rugged, uneven outline *.

The 'Egeria' visited the island in Oct. 1889. In the four years that had elapsed since its formation, a large portion had been removed by the action of the sea. Only a part (perhaps one third) of the original wide-based mound remained. This was limited for half its circumference by a cliff which was highest in the middle (153 feet), where it faced south, and subsided gradually at either end. From the summit of the cliff the surface of the mound sloped evenly downwards until it reached the level of a wide flat marked by tidal ridges, which extended round that part of the circumference of the mound not limited by the cliff. Landslips from the cliff were of frequent occurrence at high water; as many as twelve were seen in one afternoon, and the ground round the edge of the cliff was traversed by concentric cracks, showing where slices had already become loosened preparatory to their descent. Capt. Oldham erected a line of cairns at equal distances, extending from the edge of the cliff—down the slope of the mound and over the flat—as a means of measuring the rate at which the island is reduced.

The mound consisted of layers of finely-divided volcanic ash. On the face of the cliff the layers were marked by the salts which had crystallized at the surface more abundantly in some than in others, and it might be seen that each layer was thickest at the highest part of the mound, and gradually thinned out towards the periphery.

Numbers of volcanic bombs were scattered over the slope of the mound, being largest and most numerous at the highest part. These appear to have been ejected at the close of the eruption, as none appeared in the cliff-section; and the even, unscored outline of the slope negatived the idea that they had accumulated at the surface by the removal of any considerable quantities of finer materials.

The lavas presented all stages of vesicular structure, and some of the bombs displayed a distinct spiral twist in the surface ridges.

Mr. Harker † has examined the lavas and finds that they are basic augite-andesites of specific gravity 2·708.

The temperature of the interior of the mound was still high at the time of our visit. In a hole 7 feet deep a thermometer rose to 100° Fahr., while it registered 77°·5 at the surface.

To the south of the island there was an extensive shallow area with 3 fathoms of water over it. It appears that this was, in part at least, occupied by that portion of the original mound which has

* The above details are taken from an account of the island by Capt. Wharton, R.N., F.R.S., published in 'Nature' for Jan. 23, 1890 (pp. 276–278). This account is accompanied by figures and a map.

† Geol. Mag. for June, 1891, p. 250.

been removed by the action of the waves. Much of the material so removed has been thrown up on the north side of the island, forming the flat above mentioned, and an extensive shallow area beyond it.

It seems clear that unless another eruption occurs the island will in a short time be reduced again to the condition of a submarine bank formed of volcanic ashes rearranged by the action of the waves *.

It is remarkable that the depth of 1021 fathoms has been found between Falcon Island and Nomuka, the nearest of the Hapai Islands.

Next in the series come the high volcanic islands of Tofua and Kao. Tofua is a volcano in a state of intermittent activity. It is marked in the Admiralty chart as attaining a height of 1890 feet above the sea. The summit presents a fairly even outline when seen from a distance, and the sides slope steeply in all directions. The crater is situated on the northern side.

Kao is said to attain a height of over 3000 feet. It presents a singularly-perfect conical outline, from all points of view. It has not been in activity within the period of native tradition.

Continuing the line are Metis Island, which appeared a few years before Falcon Island, and is stated in the Admiralty chart to have been still in activity in 1886; and the volcano Lette, which is figured in the chart of the group (No. 2421). In 1866, when this island was visited by Lieut. Creak, R.N., in H.M.S. 'Esk,' vapour was seen issuing from the crater †.

To the north of Vavau is the volcano of Amargura. An explosion occurred in 1847, when the island was in part "destroyed by the eruption of its crater" and "ashes were thrown in large quantities on passing ships 500–600 miles to the N.E." ‡.

Northwards the line passes through Boscawen and Keppel Islands, which lie close together, halfway between Amargura and Samoa.

Boscawen Island (=Niua-tabu-tabu) is described in Findlay's Directory as one entire mountain about 2000 feet in height "resembling the Moluccas;" it is therefore probably a volcanic island.

Niua-fou (or Good Hope Island), lying considerably to the westward of these islands, is probably a member of the same series. It is described as a volcanic island with black lava rocks all round the shores, and with a crater in the middle containing a brackish-water lake. An eruption occurred in 1853, when a village was destroyed and many lives were lost. Another eruption occurred in 1867 §.

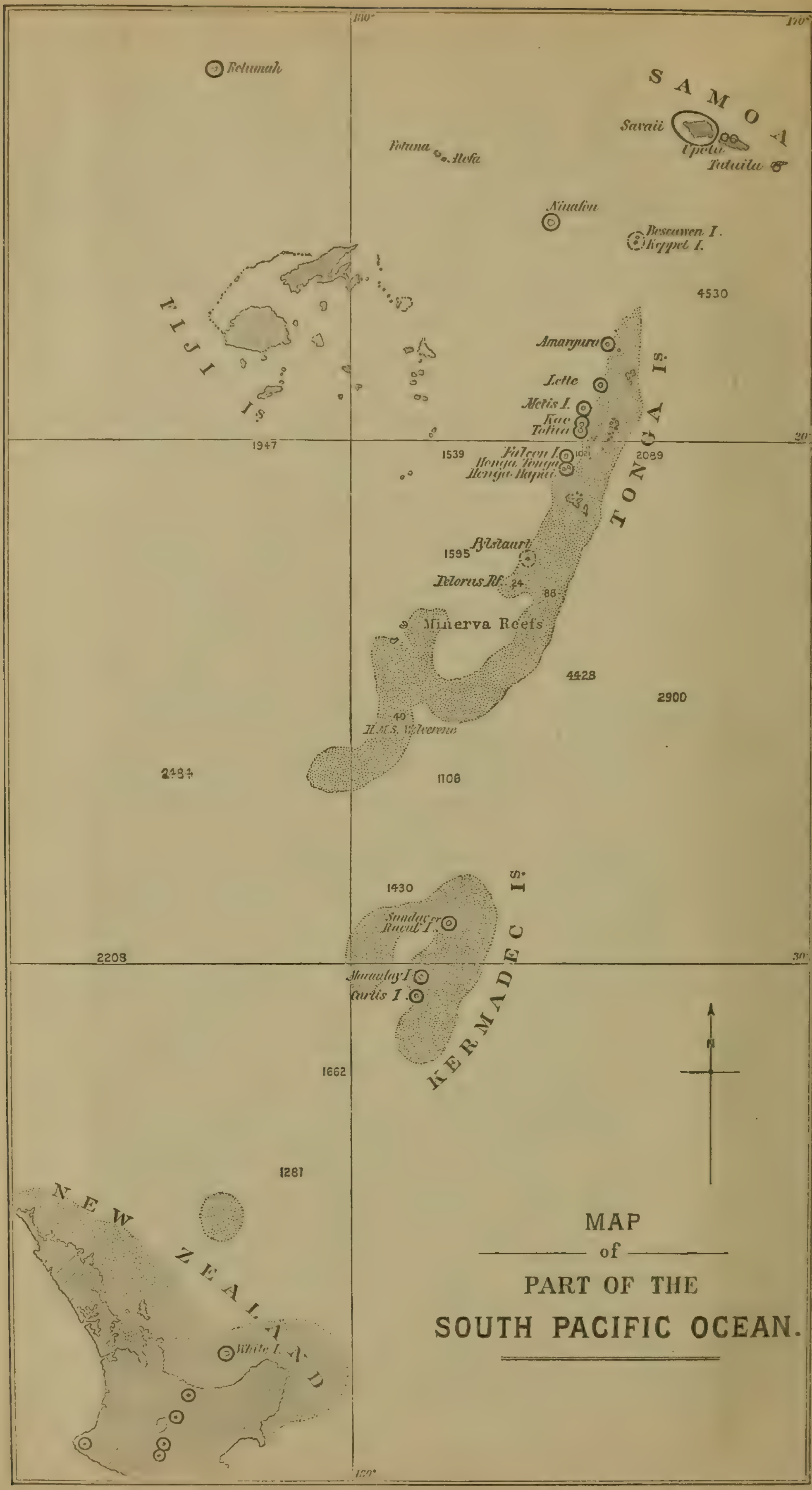
In the continuation of the direct line northward is the large volcanic island of Savaii, the most westerly of the Samoan islands. The Samoan volcanoes, however, form a series having a direction approximately W.N.W. and E.S.E., which crosses that of which the

* For a fuller account (with figs.) of the present condition of the island, see a paper by the present writer in Proc. Roy. Geograph. Soc. vol. xii. (1890) p. 157.

† Findlay, 'South Pacific Directory,' 3rd ed. p. 456.

‡ Findlay, *op. cit.* p. 456.

§ Findlay, *op. cit.* p. 558.




MAP
of
PART OF THE
SOUTH PACIFIC OCEAN.

Tongan volcanoes are members at right angles. It is significant that Savaii is the largest of either series, and is situated at the point where they intersect. Savaii ends the series in a northerly direction.

The soundings which have been taken in this part of the Pacific show that the Tonga Islands are situated on a ridge, which rises to within 1000 fathoms of the surface and is prolonged in a south-westerly direction for half the distance between this group and New Zealand. To the south of the Tonga Islands the top of the ridge reaches the surface of the sea, or comes close to it, at the Minerva Reef and three shoal patches indicated in the chart.

On the eastern side, where soundings have been taken, the slope descends to depths of over 2000 fathoms, and at two points, one to the north-east of Vavau, the other to the east of the southern extension of the ridge, the very great depths of 4530 and 4428 fathoms have been sounded.

On the west the slope appears to be less steep, but a depression (with a depth where it has been measured of over 1500 fathoms) lies between this ridge and the Fiji group.

The Kermadec Islands, lying between the southern part of the ridge and New Zealand, are the highest points of a large area which is also within the 1000-fathom line. It is, however, separated from the Tonga ridge to the north and New Zealand to the south by depths of over 1500 fathoms.

Both elevations are traversed by a line of volcanoes, which, as Mr. S. Percy Smith * has pointed out, continues the direction of that of the Taupo Zone of New Zealand. Mr. Smith suggests that the volcanoes are situated in the course of a great fissure which extends from Ruapehu, at the southern end of the Taupo Zone, through the Kermadec and Tonga groups to Samoa. This view receives some support from the fact that the eruption of Falcon Island, beginning in Oct. 1885, was contemporaneous with the increased activity (in November) of the geyser of the white terrace of Lake Rotomahana, which preceded the great explosion of Tarawera in June of the following year.

[In the map facing this page the dotted areas between New Zealand and the Tonga Islands indicate depths of less than 1000 fathoms. (The eastern limit of the Kermadec area is undetermined.)

The thick circles indicate active or extinct volcanoes, the broken circles islands whose volcanic nature is doubtful.]

### (b) *Islands formed of Sedimentary Volcanic Material.*

Belonging to this division are several islands in the Hapai Group, and the island of Eua.

The Nomuka Group, which forms the southern division of the Hapai Islands, consists of a number of small islands which are the highest points of an extensive plateau. Over a large area the top of this plateau is within 50 fathoms of the surface of the sea.

* 'Geological Notes on the Kermadec Group,' Trans. N. Z. Inst. vol. xx. p. 333.

Nomuka itself is a limestone island, and will be described later; but Mango, Tonua, Nomuka-iki, Tonumeia, and probably Kelefasia are formed of volcanic tuffs.

The island of Mango lies about six miles E.S.E. of Nomuka. The main part of the island is some two miles in length, and of an oval shape, with the long axis running east and west. Projecting to the south of the west end of the island there is a small peninsula connected with the main mass by a narrow neck. At the eastern and western ends of the island there are rounded hills attaining a height of about 150 feet above sea-level.

This island is composed for the most part of layers of volcanic tuffs which vary widely in character. The summit of the eastern hill is formed of thick and approximately horizontal layers of fine white material which is largely calcareous, but contains a fine scoriaceous residue. The western hill is composed of layers of a coarse sandstone dipping at an angle of about 2° or 3° towards the W.S.W., and consisting of rounded fragments of lava embedded in a calcareous matrix. Fragments of coral, some of them 6 inches in diameter, are mixed with the volcanic fragments. Between the two hills layers of the two kinds of rock alternate with one another.

The southern peninsula is formed of a mass of breccia traversed in various directions by cracks, but presenting no regular stratification. The fragments are embedded in a calcareous matrix and vary greatly in size. Lying on the surface are some large boulders, some of coral, some of volcanic rock, which appear to have been isolated by the gradual removal of the finer material in which they were embedded. The largest of these was a rounded mass of coral which measured 10 feet in length, 7 feet in breadth, and $3\frac{1}{2}$ feet in height. In the cliff which surrounds this part of the island, fragments of coral were thickly scattered among the volcanic constituents. I counted 43 pieces exposed in one square yard. Though Mango is surrounded by a broad fringing reef, I failed to find any raised coral-rock upon it.

The island appears to have been originally formed as a submarine bank, probably of volcanic origin, on which corals grew. On a return of volcanic activity the coral-reef was broken up, and the fragments of it mixed with the volcanic materials have formed the breccias of which the island is composed.

It appears that the southern promontory was the nearest point of the present island to the centre of the eruption, for there the constituents of the breccia are largest and mixed indiscriminately without stratification. The nearly horizontally stratified rocks on the eastern and western hills were laid out now in finer, now in coarser layers by the action of the water. The island has subsequently been elevated to its present height, the rounded outline of the hills being due to subaerial denudation.

It is remarkable that while the island is now surrounded by flourishing coral-reefs, there should be no old raised reef upon it. The most probable explanation appears to be that elevation took place too rapidly to allow of the growth of reefs of any considerable extent.

Some miles to the westward of Mango is the small island of Nomuka-iki (=little Nomuka), to the south of Nomuka, and separated from it by a narrow channel. This island is about 60 feet high, and one mile in its longest diameter; it also is formed in part of a hill of volcanic tuff, the remainder consisting of a flat of calcareous sand. The layers are horizontal and are made up of finer and coarser beds of brown and grey ashes alternating with one another. Here there are no fragments of coral mixed with the ashes. A fossil univalve of the genus *Pyrula* occurred in these beds, and some of the finer ones contained vertical burrows (of an annelid?) which were filled in with the coarser material of the overlying layer.

As at Mango, there are no raised coral-rocks overlying the volcanic beds, although broad fringing reefs surround the shores.

The beds have evidently been laid out by water, but under quieter conditions than those of the neighbouring island, and the mound has since been elevated to its present height.

A little to the south of Mango are the two islands Tonumeia and Kelefasia. Capt. Oldham visited Tonumeia when engaged in the survey of the group in 1890. He found it to consist of volcanic tuffs forming a cliff 80 feet high, and dipping at an angle of 3° to the south *. Mr. Harker finds that a specimen of these beds consists of "fine volcanic ash compacted by a calcareous and ferruginous cement into a yellow-brown rock."

Capt. Oldham also obtained some black nodules two inches in diameter, with portions of a calcareous matrix still adherent, and which had presumably weathered out of the layers of tuff. Mr. Harker describes these as consisting of oxide of manganese having "the general characters of psilomelane, but soft and of a low specific gravity, and therefore perhaps altered."

The presence of these nodules, supposing them to have occurred naturally in the beds of which Tonumeia is composed, is very remarkable. They are generally supposed to be formed only in deep water; but the situation of the island on the same shallow plateau as Mango and Nomuka-iki, and the general correspondence of its formation with theirs, point strongly to the conclusion that these islands were all formed under similar conditions. The presence of coral and other organic remains amongst the volcanic constituents of these islands shows that they were formed in shallow water.

Judging by its appearance as seen from the sea, I have little doubt that Kelefasia belongs to the same class of islands.

The island Tonua, to the north-east of Mango, was also examined by Capt. Oldham. It is composed of yellowish-white rocks which form a cliff twenty feet high, and consist of volcanic ashes with little calcareous matrix, though shells of pteropods and the cast of a gasteropod (*Murex*?) were found among the volcanic fragments †.

In the central part of the Hapai group there are two islands,

* The substance of Capt. Oldham's report on this island and Tonua is given in Mr. Harker's paper in the Geol. Mag. for June, 1891.

† Harker, *op. cit.*

Kotu and Matuku, which, as seen from the sea, appeared to me to be of the same nature as those above described in the Nomuka group. The only confirmatory evidence that I can offer is a remark on the island of "Kotoo" in the narrative of Capt. Cook's Voyage to the Northern Hemisphere (vol. i. p. 271), where it is stated that this island "terminates in reddish clayey cliffs."

Leaving the Hapai Group, I will now attempt to describe the island of Eua, lying to the south-east of Tongatabu. (For the map of this island, see Pl. XXIII.) Eua is somewhat oval in shape, but pointed at the two ends; the long axis is directed almost exactly north and south. It is about $12\frac{1}{4}$ miles long, rather more than 4 miles broad, and attains a height of 1078 feet. The island is formed of a basis of volcanic rock, in great part covered by limestone. A ridge of high ground traverses the island from north to south, attaining a height of over 1000 feet at two points, one near the middle of the ridge, the other about four miles to the south. Between these two points the general level of the ridge is from 800 to 1000 feet. The volcanic formation comes to the surface over a great part of this high ground, and where it is bare of vegetation is readily recognized by its bright red colour; but patches of limestone occur in many places, sometimes in large projecting masses, like that which forms the south summit, sometimes weathered down into groups of isolated pinnacles standing on the volcanic basis.

Northward the ridge descends gradually to an elevation of about 500 feet and extends at this level, as a long flat-topped plateau or terrace, to the north end of the island. This will be referred to as terrace *b*. The volcanic basis appears in irregular patches along the centre, but its eastern and western sides are bordered by cliffs of limestone, some 200 feet in height, whose base evidently marks an old shore-line at a previous stage of elevation of the island.

The whole eastern side, presented to the trade wind, is very abrupt, and rises in range above range of limestone-cliffs, the steep slopes between them being covered with dense wind-swept forest. The descent is interrupted along the greater part of this aspect by a narrow terrace, from which on the one hand perpendicular cliffs descend to the sea, and on the other a slope of débris leads to the foot of the range of cliffs which limit the central ridge along its whole length. This terrace is, however, absent opposite the middle of the eastern aspect, and here a steep slope extends directly from the foot of the higher range of cliffs to the sea. The volcanic basis is exposed on this slope, and at the shore are projecting dykes of intrusive rock. Farther to the south the terrace is again interrupted by a break occupied by a small terrace at a lower level. At this point also a dyke appears on the shore at the foot of the cliffs.

Along its western aspect the central ridge is well-defined at the northern and southern ends, being bordered by limestone cliffs. The middle part of this aspect is broken up by small valleys which

take their origin in the highest part of the island, and here the volcanic basis is largely exposed. A wide terrace of limestone standing at a level of 250 to 350 feet extends along the whole of the western side of the island, spreading out from the lower slopes of the central ridge. This will be referred to as terrace *a*. It is widest opposite the middle of the island, becoming narrower to north and south, and forms nearly half the total area of Eua. From its western border the land slopes more or less steeply to the sea.

The western aspect of the island offers a marked contrast to the eastern. Instead of the dense wind-swept forest, there are wide open stretches of grass-covered country, intersected here and there with belts of luxuriant bush. The streams which have scored the western slopes of the central ridge dip underground on reaching the limestone terraces and pursue a subterranean course to the sea. There are, however, continuing some of the stream channels, deep gorges cut in the western terrace, whose sides descend abruptly from the general level; these are overflow channels, in which water runs only after heavy rains.

There is one stream, possibly there are others, in the higher part of the island, which pursues a different course. At an elevation of about 620 feet there is a funnel-shaped depression in the volcanic deposits; and at the bottom of this funnel a vertical shaft descends several hundred feet into the interior of the island. Its mouth measures about 100 feet in one diameter and 30 feet in the other. After flowing down the side of the depression the stream falls into the shaft, pouring over the layers of hardened tuff at one end of the long axis of the opening. The mouth of the shaft is surrounded by trees, festooned with creepers which hang down into it, and a mist rises, carried upwards by the return currents of air. The native name of the place is "Ana-ahu" (=Smoky hole). It would appear that a crack was formed during the upheaval of the island, which has been gradually enlarged at this spot by the action of the stream.

The volcanic basis of Eua appears to consist very largely of fragmentary accumulations arranged in strata. At the mouth of the "Ana-ahu" (about 620 feet above the sea) the layers are horizontal, and composed of moderately coarse fragments. Between layers of a purely volcanic nature there occur others which are hardened by a cement of calcite, in which, besides the volcanic fragments, foraminifera and other organic remains are embedded *.

Dr. John Murray finds among the organic remains "many pelagic foraminifera, and pelagic molluscs such as pteropoda and heteropoda; also a few ostracoda and fragments of bottom-living molluscs. Among the foraminifera *Globigerina rubra* and *bulloides* and other Globigerinæ are most abundant." Dr. Murray concludes that "these rocks were evidently laid down in deeper water" than the limestones investing the volcanic basis.

* Slide No. 1268 in the collection at the Woodwardian Museum, Cambridge.

Among the volcanic fragments Mr. Harker has detected red garnet and tourmaline, whose presence indicates the existence of metamorphic rocks somewhere in the vicinity.

A similar partly calcareous rock occurs at the northern end of terrace *b*, where the volcanic basis is exposed *.

The uppermost part of the volcanic formation consists of red, yellow, and brown beds of ashes, which are very much decomposed by weathering. Some are nearly horizontal, others a good deal contorted, but they are never, so far as I observed, regularly inclined at an angle, as though they had formed part of a volcanic cone.

As mentioned above, dykes of intrusive rock project on the eastern shore. They are composed of augite- and hypersthene-andesites. Large rounded boulders of this rock, mixed with boulders of coral, form the shore, and the natives obtain here the hard rounded stones which are used for pounding the root of the kava plant, in the preparation of the beverage of that name. The dykes penetrate the beds of tuff and form well-marked projections at the surface ; they do not, however, penetrate the overlying limestone.

Besides the intrusive rocks there is a crystalline, plutonic rock in this part of the island, of which I obtained a specimen from a boulder on the shore. Mr. Harker describes it as "uralitized gabbro." Although I did not find this rock *in situ*, I have no doubt that it exists as a natural constituent of the island. It is highly improbable that a boulder should be brought here by artificial means, for there is no possible landing-place for vessels along the whole of this eastern coast, and the only access to it from the anchorage on the western side is by steep hill-paths. A reef about 100 yards wide stretches out from the shore, and on the edge of this reef a vessel would strike, supposing one to be wrecked. I think therefore it may be concluded that the rock occurs naturally on the island.

The volcanic basis of Eua appears to have been produced by an extensive submarine eruption which formed a mound of considerable extent, and into which lava was injected.

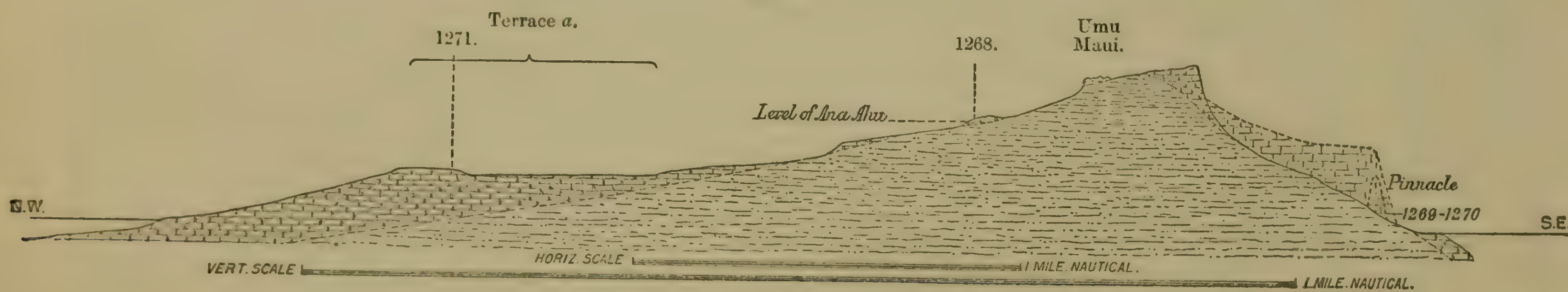
The eruption seems to have occurred at some depth, for the organisms found mingled with the volcanic materials are, according to Dr. Murray, pelagic and not shallow-water forms. Subsequent to its formation and the cessation of the volcanic forces, but prior to the deposition of the overlying limestones, the mound was elevated to at least its present height and considerably denuded. The evidence for this denudation is afforded by the elongated shape, and the steepness of the eastern slope of the volcanic basis which underlies the limestone ; these imply the removal of a considerable part of the original mound, which is built up in the main of horizontal layers. After its denudation the island subsided again, before the deposition of the limestone formation.

The limestones invest nearly the whole of the lower part of Eua up to a level of about 500 feet, and above this level they occur, though less continuously, as high as the summit.

* Slide No. 1273.

*Diagrammatic Sections across Eua (Tonga Islands).*

Fig. 1.

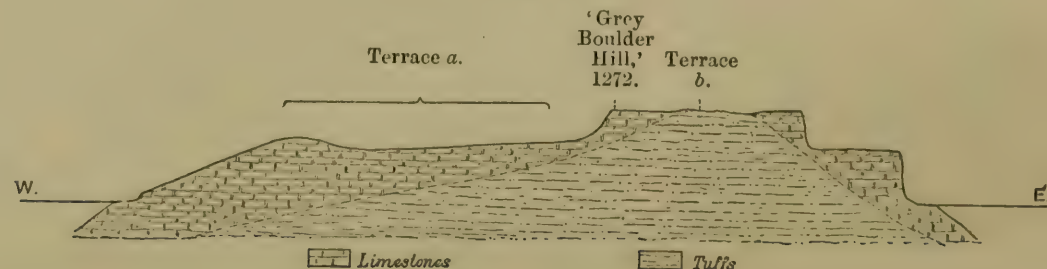



EXPLANATION.

Fig. 1. Section passing E. and W. through the summit. At the S.E. end the country lying to the N. of the section is indicated, to show the position of the Pinnacle from whose base specimens Nos. 1269 and 1270 were taken.

Fig. 2. Section E. and W. through the island, to the north of the summit. The position of terrace *b*, 'Grey Boulder Hill,' is shown.

Fig. 2.



The most striking feature of the formation is the existence of well marked terraces on the lower slopes.

The terrace *a*, as above stated, extends along the whole length of the western side of the island, at an elevation of about 250 to 365 feet above sea-level.

The outer, western border of the terrace is for a great part of its length higher than the interior. Beginning at the northern end, we find the terrace forming a narrow band, so narrow that it makes only a slight interruption in the sloping side of the island. To the south it gradually widens out, being at first level from side to side, but soon the interior becomes depressed below the margin. The depression is greatest at one-third of the length of the island from north to south. Here the margin is about 65 feet higher than the interior. As we advance southward the depression of the interior becomes less marked, until at the junction of the middle and southern thirds of the length of the island the terrace is again level, and remains so to the southern end. Passing across the terrace from east to west, in the region of the depression we descend a very gradual slope to near the outer border. From the lowest part the ground rises to the margin of the terrace, in most places by a gradual ascent, but at one point the rise is abrupt. Opposite the town of Ohunua there is a gap in the high margin, the bottom of which is at the same level as the depressed inner part of the terrace. Through the gap there runs a steep-sided ravine, cut in the limestone rock; it is formed by the junction of two of the overflow channels of the streams of the upper part of the island, and there is water in it only after heavy rains. Having passed the gap the ravine pursues a straight course down the sloping side of the island to the sea, and at its mouth there is a break in the reef and an anchorage for small vessels.

On the margin of the terrace to the south of the gap the limestone rock forms projecting masses, and in some of these definite *Astræa*-like coral structure is to be seen. Other specimens present a homogeneous structure to the naked eye. Dr. Murray has examined sections of these *, and finds that they are "chiefly made up of calcareous algæ, together with fragments of coral, molluscs, echinoderms, and foraminifera" †. He concludes from the character of the organisms that the deposit was "formed in quite shallow water."

With regard to the peculiar conformation of the terrace, it appears that the depression in the interior must either have existed at the time that the terrace was elevated above sea-level, or have been excavated since by the denuding action of rain or streams.

Slide No. 1271.
Among the foraminifera the following kinds were recognized:—

| | |
|---|---|
| *Miliolina*, sp. | *Planorbulina larvata* (P. & J.). |
| *Orbitolites duplex* (?).. | *Carpenteria monticularis* (Carter). |
| *Textularia trochus* (d'Orb.). | *Polytrema miniaceum* (Linn.). |
| *Globigerina bulloides* and *Gl. rubra* (?). | *Calcarina hispida* (Brady). |

In ordinary weather the streams flow beneath the limestone rock, and it is only after heavy rains that running water is found in the ravines which traverse the terrace. Moreover, the sides of these slope abruptly down from the level of the terrace, and their course is for the most part quite independent of the direction of the depression. Finally, it may be asked, Why should the drainage from a flat area excavate the interior and leave the margin comparatively untouched along almost the entire length of the terrace? It appears, then, that the terrace had much the same general conformation which it now presents when it was upraised from the sea; in other words, that the elevated border constituted a small barrier-reef lying nearly a mile from the shore of the island as it then existed, with a break in it at one point, and enclosing a lagoon with a depth of 6 fathoms over a considerable area. At its northern and southern ends the reef joined the shore and became fringing. A similar relation of reef to shore occurs in the reefs now forming the harbour of Suva in Viti Levu, the capital of Fiji, where the barrier which protects the anchorage is continued into a fringing reef along the southern shore of the island.

As above described, there is a narrow limestone-terrace running along the eastern side of the island at about the same level as terrace *a* on the western, and interrupted in the middle by a deep gap, the head of which is formed by the cliffs of nearly the highest part of the island. On the north of the gap the terrace ends abruptly in a cliff, facing south, and standing out beyond the cliff is an isolated pinnacle of limestone rock, which I estimated as measuring about 300 feet from top to bottom. The rock of the base of the pinnacle presents to the naked eye a compact homogeneous structure, except that in one specimen there is a cavity which was occupied by a univalve of the genus *Cerithium*. Dr. Murray has examined sections of the rock * and finds that it is made up principally of calcareous algæ, together with fragments of echinoderms, molluscs, and a number of foraminifera †.

The limestones of terrace *b*, which stands at an elevation of about 500 feet, are also for the most part homogeneous compact rocks. A section from the edge of the terrace ‡ is found by Dr. Murray to be "chiefly made up of calcareous organisms. Fragments of molluscs, echinoderms, polyzoa, and calcareous algæ, together

* Slides 1269 and 1270.

† Viz.:—

| | |
|---|---|
| *Spiroloculina*, sp. | *Polytrema miniaceum* (Linn.). |
| *Bulimina* (cf. *compressa*). | *Rotalia*, sp. |
| *Bolivina textilarioides* (Reuss). | *Tinoporus bacculatus*. |
| *Textularia trochus* (d'Orb.). | *Cymbalopora Poeyi* (d'Orb.). |
| *Cristellaria*, sp. | *Gypsina inhærens* (Schultze). |
| *Globigerina* (*rubra* ?). | *Cycloclypeus Carpenteri* (Brady). |
| *Truncatulina*, sp. | *Heterostegina depressa* (d'Orb.). |
| *Planorbulina* (cf. *larvata*). | *Nummulites Cumingii* (Carpt.). |

‡ Slide No. 1272.

with a large number of foraminifera" *. True coral does, however, exist on this terrace, as I found one large mass clearly exhibiting a structure like that of a *Porites*.

The limestones from the higher part of the island present for the most part a compact structure. Some of them are crowded with foraminifera, but large masses of coral appear to be absent.

With regard to the nature of the limestone formations as a whole, as indicated by the sections above described, Dr. Murray writes to me that they "may all have been formed in or about reefs, and true coral-reefs may have been living quite close to them when they were laid down;" but from the scarcity of examples of the larger corals he concludes that "it is more likely that they were laid down in depths of from 30 to 100 fathoms, and that they formed the base of true coral-reefs."

The conformation of the surface of terrace *a* points to its having formed a true reef, and having been elevated without much denudation; but in the case of terrace *b* and the higher limestone rocks, the extent to which they have evidently been denuded and their nearness to the volcanic basis bear out Dr. Murray's view, founded on the nature of the organisms they contain.

Some features of interest are presented by the shores of the island.

On its western side, in the neighbourhood of the village of Ohunua, the island is bordered by a narrow fringing reef some 50 to 100 yards in width. There are clear traces here of recent elevation. To the south of the village there is a low shore-cliff undermined by the action of the sea, but separated from the present shore by a strip of sand some 50 to 60 yards wide, covered with cocoanut palms and other trees.

From a little to the north of the village the island is bordered by a cliff some thirty feet high, which extends to the northern end. The foot of this cliff is washed at high tide by the sea, and is deeply undermined, the upper limit reached by the action of the sea being sharply defined. Above this present line of undermining, and separated from it by a projecting ledge of rock, there is another and older one, the upper limit of which is sharply defined and separated from that of the present line of wave-action by a distance of seven feet. When looking at the cliff from the sea, I thought I detected a third line of wave-action at a still higher level.

From the foot of the cliff the shore-platform extends some fifty to a hundred yards, and is bordered by growing coral. Over the greater part of its extent this platform is flat, and at high tide is

* *Miliolina*, sp.
*Orbitolites complanata* (?).
*Textularia trochus* (d'Orb.).
*Polymorphina*, sp.
*Globigerina* (*bulloides*?).
*Truncatulina*, sp.
*Planorbulina larvata* (P. & J.).
*Carpenteria monticularis* (Carter).
*Polytrema miniaceum* (Linn.).
*Gypsina inhærens* (Schultze).
*Rotalia*, sp.
*Calcarina hispida* (Brady).
*Cycloclypeus Carpenteri* (Brady).
*Heterostegina depressa* (d'Orb.).
*Nummulites Cumingii* (Carpt.).

covered by about two feet of water. In some places, however, there are the remains of the shore-platform which was formed when the island stood at a lower level, and corresponds with the higher line of undermining seen in the cliffs above. Its upper surface is above the level of high water, and is worn into irregular shapes. It is overgrown in some places by a small shrub (*Pemphis acidula*).

These features point clearly to recent elevation, and the distance between the two lines of undermining seen on the cliff shows that the extent of this was 7 feet. Further, it is clear that the elevation took place rapidly, at least as measured by the rate at which the sea is wearing back the cliffs, for if it had been accomplished slowly, in comparison with that measure, the rock which forms a projecting ledge between the two levels of excavation would have been worn back during the elevation.

It is interesting also to note that if the island were to remain at the level it occupies at present, all traces of the recent elevation would in time be obliterated, for as the cliff was worn back the rock bearing the impress of the action of the waves when the island was at the lower level would be removed, while the remnants of the older reef-platform would be worn away to the level of the present one.

It may further be observed that a reef-platform such as this consists of two distinct parts—an outer formed by the growth outwards of the existing reef, and an inner formed of the base of the older and elevated reefs, whose higher portions have been removed by the action of the sea.

At the south end of the island there is no reef; deep water extends to the foot of the cliffs.

A narrow fringing reef, some hundred yards wide, extends along the eastern side of Eua. Its upper surface is above the level of high water and partly worn away by the sea, offering evidence of the recent elevation of the island, corresponding to that found on the western shore. The margin of the reef is exposed to the full force of the rollers coming up before the trade wind, and presents a remarkable basin-like growth of corallines similar to that found on the southern side of Tongatabu, to be described later.

At the south end of the eastern shore of Eua there is a remarkable instance of the different manner in which the volcanic and limestone rocks are excavated by the action of the waves.

A narrow terrace, perhaps a quarter of a mile broad, runs round this end of the island, standing at a level of some 240 feet above the sea. It is bordered by cliffs which go sheer down into deep water. Limiting it on the land side there is a steep ascent to a higher terrace above.

The limestone rock here lies on the steeply sloping surface of the volcanic basis of the island. The outer or sea border of the terrace and nearly the whole face of the cliff are formed of limestone; but at the inner border of the terrace, and here and there in the lower part of the cliffs, the volcanic basis is exposed. At one point there is a large circular chasm excavated in the terrace which descends to sea-level and communicates with the sea by a

wide opening, overarched by a natural bridge of the limestone rock, the under surface of which is festooned with stalactites. The sea entering beneath the arch washes the bases of the nearly vertical sides of the chasm. The place is called by the natives Matalanga Maui (or the hole made by the implement for planting yams belonging to the god Maui). The manner in which the chasm has been excavated appears obvious. At the foot of the cliffs there are several caves in different stages of excavation, which are formed by the sea wearing back the volcanic rock where it is exposed beneath the limestone. The Matalanga Maui has been formed by the removal of the volcanic rock to such an extent that the cave has approached the surface of the terrace and the roof has fallen in.

I may here recapitulate the main features which seem to be indicated by the structure of Eua.

The presence of the plutonic rock points to the existence of an ancient and much denuded mass of such a character in the vicinity.

In the neighbourhood of this mass, and at a considerable depth below the surface of the sea, a volcanic eruption occurred, forming a mound, some of whose upper layers were mingled with pelagic organisms as they were laid out.

It appears that the mound was elevated above the surface, considerably denuded, and afterwards depressed to such a depth, at least, as to submerge its summit.

A covering of calcareous organisms was deposited on the volcanic basis while it was submerged; but so far as the evidence goes the formation is a shallow-water one. The island has since been again elevated by stages to the present height.

During periods when the elevatory forces were in abeyance, the sea wore back the already emerged limestone-deposits, forming terraces bounded by lines of cliff, but in one case at least (namely, the western terrace *a*) it appears that a true coral-reef was formed in the neighbourhood of the shore.

Dr. Murray finds that it is impossible to assign the organic deposits of the island to a definite geological epoch. Though he is of opinion that they are old, there is no satisfactory evidence to refer them to the Tertiary period.

### (c) *Islands formed entirely of Limestone.*

The islands forming the remarkable group of Vavau differ widely in their shape and arrangement from coral islands in general.

Vavau consists of one large island which gives its name to the group, and of a number of smaller islets (see Pl. XXIII.). Vavau Island presents a high and fairly even coast-line to the north and north-east, bordered by limestone cliffs from 300 to 500 feet in height. On the south and south-west the general lie of the land is lower than that on the northern coast. Long promontories stretch out from the main mass of the island, separated by narrow and deep

arms of the sea. The islets are grouped about this coast, in some cases continuing the lines of the promontories. The beautiful and secluded harbour of Neiafu is bounded in part by two of these promontories, and protected from the sea by one of the larger islets situated between them. It forms a long basin more than 20 fathoms deep over the greater part, and almost entirely surrounded by land over 100 feet in height.

The surface rock all over the group consists, so far as I am aware, of limestone. I was unable to find the underlying basis at any point. Even at the foot of the high cliffs on the northern shore the rock, at the two points at which I saw it, was of this nature, and I found no fragments of volcanic or any other formation than limestone on the beaches. Although I saw no vertical cliff at this part of the island, extending from the top to the shore, the coast-line is in many places so steep that I have no doubt that the formation attains a thickness of at least 300 feet. It consisted for the most part of a hard homogeneous material, but at one point, in the lower part of the cliff, numbers of large bivalve shells were embedded.

The main mass of the island presents an undulating surface, gradually sloping from the high northern border towards the south. Though there are valley-like depressions in several places, I came upon none which contained streams or even ravines. Springs of fresh water issue from the rock at many points on the shore.

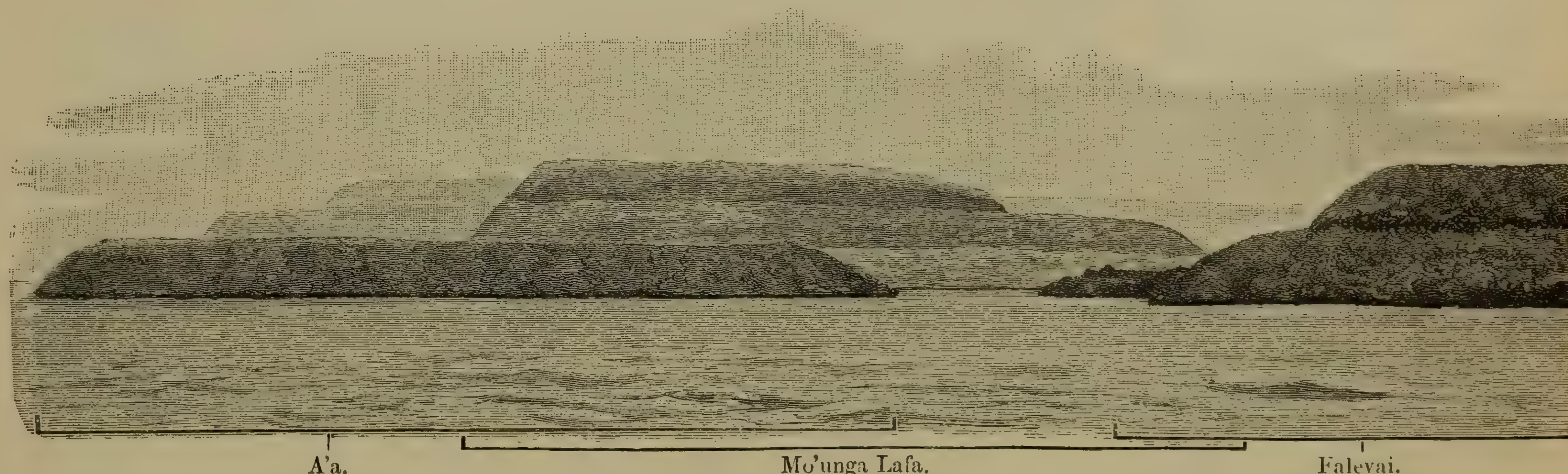
The outlying islands to the south of the group, as may be seen by the Admiralty chart (No. 2357), are surrounded by coral-reefs, which in many cases extend as broad expanses far from the island with which they are connected. As the inlets penetrate among the islands and promontories, and their shores are cut off from the open ocean, the reefs become narrower or disappear; though in some cases (as in the inlet to the north of the promontory in which Neiafu is situated) there are coral reefs of considerable extent growing far up in the sheltered channels.

There is one feature which at once strikes a visitor approaching the group by the usual steamboat course from the south-west and passing up to the harbour of Neiafu, namely, that the off-lying islands and projecting points of the main island, on either hand, are flat-topped when seen in profile, and that the majority of them stand approximately at one of three levels of elevation above the sea. Corresponding in level with the tops of the lower islands there are, moreover, terraces on the sides of the intermediate and highest ones; and in the same way there are, on the sides of the highest points of land, terraces whose level corresponds with the tops of the islands of an intermediate height.

The islands and promontories may thus be described as being one-, two-, or three-storied (see fig. 3).

On first entering the group, the flat one-storied islands Hunga and Nuipapa lie on either hand: their sides drop vertically into the sea and are deeply undermined below by the action of the waves. Right ahead stands up the mass of Mo'unga Lafa (=Flat Mountain), whose densely wooded sides present two well-marked terraces in

Fig. 3.—*View among the Islands to the South of Vavau.*



their descent to the sea. Opposite it, on the right of the passage is the island of Falevai (called "Kopa" in the Admiralty chart), which consists in part of a two-storied mass, in part of a one-storied tongue of land which extends out towards Mo'unga Lafa, while a terrace at the same level interrupts the slope on the side of the higher part of the island. Small islands are dotted over the sheltered expanse of water, two of which, A'a (called "Koto" in the chart) and Langito'o, present features of interest which will be alluded to below. As we advance, the hill Talau comes into view, exactly repeating the shape of Mo'unga Lafa, in the level outline of the summit and the two lines of terraces on its sides.

The rough aneroid measurements that I obtained give about 140 feet as the upper limit of the first "story," 260 to 350 feet as that of the second, and 420 and 520 for the summits of Talau and Mo'unga Lafa, the two highest points of land in this part of the group. Although these numbers show that the levels of the terraces at different points do not agree accurately, the conclusion was strongly impressed upon me on the spot, that the terraces and islands at each level do in fact correspond, that is, that at successive stages in the elevation of the group, the summit of each "story" has stood at sea-level. The differences in their level may be in part accounted for by the unequal action of the elevatory forces at different points of the area acted on. Thus, on the hills Talau and Mo'unga Lafa, which are between three and four miles apart, while the summit of the lowest story is at about the same level in each (140–150 feet), the two upper ones stand at about 270 and 420 feet in Talau as against 360 and 520 feet in Mo'unga Lafa. From this it appears that the second elevation was of greater extent in the neighbourhood of Mo'unga Lafa than to the eastward near Talau.

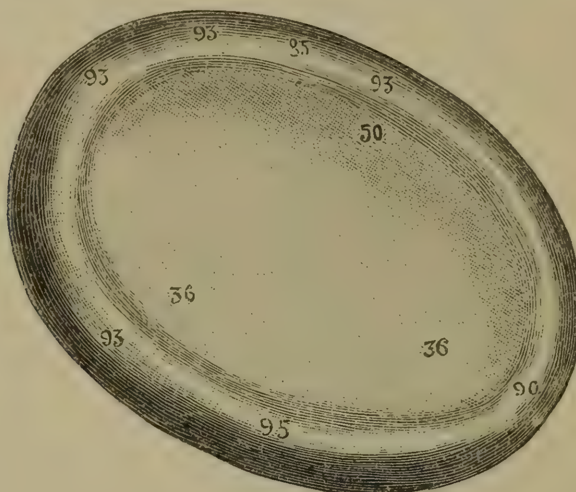
One remarkable feature in the contour of the land is the fact that in some cases the summits of the islands, though level in profile, are excavated by well-marked depressions.

The most perfect example of this structure is presented by the little island of A'a (the Koto of the chart) above mentioned. The island is of an oval shape, being about three quarters of a mile long and half a mile broad. It rises out of deep water, and is not surrounded by a reef. In the chart a sounding of over 40 fathoms is shown close to the southern shore, and except for a small shallow area at the eastern end the other soundings in the neighbourhood indicate nearly as great or greater depths.

The sides slope steeply up to a height of from 85 to 95 feet (an elevation considerably less than that of the top of the first "story" in the surrounding islands), but the interior of the island is depressed 50 or 60 feet below the level of the margin, being occupied by a flat which stands at a height of some 36 feet above the sea. The margin is of a nearly uniform height and forms a complete unbroken ring. On its summit rough masses of limestone rock stand up, but the flat interior is formed of brown earth. It seems clear that when the rock forming the edge of the island stood at sea-level a small lagoon some 10 fathoms deep occupied the centre.

I was led to visit A'a by seeing its depressed interior from the top of Mo'unga Lafa. From that position the neighbouring island Langito'o, to the west of A'a, which rises to about the same height, appeared to have a similar depression in it. Unfortunately I had no opportunity of visiting this island.

Fig. 4.—*Sketch of the contour of the island of A'a* (*Vavau Group*).

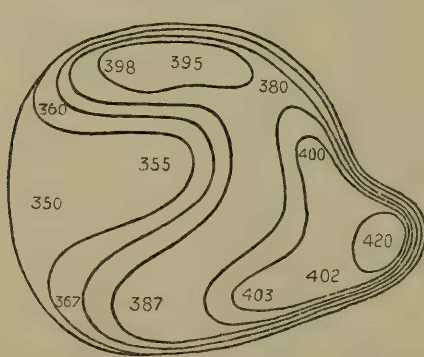



The numbers indicate heights, in feet, above the sea.

The summit of the three-storied hill Talau, near Neiafu, presents similar features. Here, too, a high margin surrounds a central depression, but the margin is complete for only three quarters of a ring. For the other quarter the level of the margin descends to that of the interior.

The accompanying rough map of the summit of the hill shows

Fig. 5.—*Sketch of the contour of the summit of Talau* (*Vavau Group*), *Tonga Islands.*




The numbers indicate heights, in feet, above the sea.

the contour. From this it is seen that the bottom of the depression lies some 40 to 50 feet below the higher part of the margin.

The summit of the other three-storied hill, Mo'unga Lafa, is, I believe, as the name implies, flat. The uniform covering of bush obstructs any general view of it; but in traversing it I was unable to find any depression corresponding to that in the summit of Talau.

In the short visits that I paid to the Vavau Group, I landed on a few only of the islands, and had not the means of making satisfactory observations of contour. I have drawn attention to the features above described, with the hope that when the survey of the Tonga Islands which was begun by H.M.S. 'Egeria' is continued, the heights and contours of the islands and terraces occurring at different levels in this remarkable group may receive special attention.

The peculiar shape of the group, penetrated by long, narrow, and deep inlets of the sea, may perhaps be accounted for by supposing a much-denuded basis, probably of volcanic nature, whose surface was deeply scored by valleys previous to its subsidence. While the island was submerged the deposits which formed the limestone rock were laid down, and the lower layers would have already begun to accumulate during the downward movement. But, though the base of the limestone deposit may very probably have been formed during subsidence, the upper part and the contour of the land must be chiefly referred to the succeeding period, which has, in the main at least, been one of elevation.

During intervals in the elevation, the terraces and plateaus which constitute so marked a feature have been formed, first on the highest and later on the lower peaks and ridges, while the intervening valleys still penetrate far among the islands and promontories.

It is interesting that, both at Vavau and at Eua, the reefs which have been formed during intervals in the elevation of the islands have in some cases acquired atoll- or barrier-like contours.

The larger islands of the Hapai Group lie in a line extending from Haano in the north to Uiha and Alefa in the south. They are indeed the elevated parts of a long reef, which, after extending in a south-westerly direction for some 30 geographical miles, sweeps round in an even curve to the west and north-west, and is finally lost among the reefs and islands of the Kotu Group. At two points in the northern part of the reef, gaps are indicated in the chart. The northern of these is bordered by reefs which are continued for a considerable distance in a westerly direction. To the south of the southern part of this reef there is an outer and more interrupted line of reef concentric with it. On the convex or weather side the margin of the reef is even, but on the opposite side the coral grows in irregular patches and the margin is ill-defined.

The island of Lefuka may be taken as a type of the islands situated on the reef. It is about three quarters of a mile in breadth, and some three or four miles in length. From the beach on the western side there is a very gradual slope towards the eastern side of the island, which is about 20 feet above high water. Near the

eastern side there is a rather rapid descent, terminating in a little cliff some 10 feet high, whose base is much excavated by the waves. The rock of which the cliff is made consists of masses of coral of various sizes, cemented together into a conglomerate. Its structure, in fact, resembles that of a shore-platform. Extending from the foot of the cliff some 300 yards to seaward is the present shore-platform, on which, at low tide, there is about a foot of water near the shore, while the outer part lies bare. The cliff of raised rock extends along the whole of the eastern shore of the island.

Some distance from the concave side of the long Hapai reef there are numerous shoals and small islands. The island of Fotuha, north of the Kotu Group, displays the abrupt undermined cliffs of a raised coral-island, and stands at an elevation of about 100 feet above the sea.

The few soundings that are given in the chart show depths of 10 to 24 fathoms along the greater part of the western boundary of the reef, though 30 fathoms is marked opposite the northern break in the reef above alluded to, and 56 fathoms within its northern border.

The Kotu Group consists of a number of small islands, from whose shores considerable tracts of reef extend at sea-level.

The only island of this group on which I landed was Hafeva. I found no raised coral-rock, but a loose sandy formation which attained a height of some 12 feet at the shore. The interior of the island is depressed and occupied by a marsh. There is a wide gap among the reefs on the western side, with a depth of some 8 fathoms, forming an anchorage which was at one time used by whalers. Of the other islands of the Kotu Group, three show the deeply undermined cliffs characteristic of raised coral-islands; but two of them, Kotu and Matuku, as already stated, recall, in their reddish-brown cliffs and peculiar outline, the tuff islands of Mango and Nomuka-iki of the southern part of the Hapai Group (see p. 598).

It seems clear that the long reef of the Hapai Group must be regarded as a barrier-reef or an imperfect atoll. The shoals and islands situated within the concavity of the reef, both the northern ones and those of the Kotu Group, probably either rest on or are parts of the mass on whose eastern and southern slopes the reef has grown, and the volcanic character which I thought I recognized in two of the latter offers some evidence as to the kind of formation of which the basis is composed.

The outer line of reefs, lying some four miles to the south of the main one, and concentric with it, is a very remarkable feature. Its relation to that reef seems to imply that it is of an older date, and accords very well with the view that the reefs are slowly growing outwards on the slopes of a submerged mound. It must be observed, however, that in the northern part of the great reef, in the neighbourhood of the larger islands, there appears no reason for supposing that the reef is moving away from the centre of the group, for it is bordered by flourishing coral-reefs on the western as well as on the eastern side.

The raised reef-platform of which the islands to the north are formed, as well as the raised coral-island Fotuha, and those of the Kotu Group, show that elevation has taken place, though only to a comparatively small extent, in the northern and western parts of the group. On the other hand, the absence of islands of any considerable size from the southern parts of the reefs appears to indicate that this region was not affected by the elevation.

The island of Nomuka in the southern part of the Hapai Group is triangular in shape, the sides, which are about equal, measuring some 2 miles in length. To the south lies the little island Nomuka-iki, separated by a channel a mile and a half wide, and 15 fathoms deep.

A large shallow lagoon occupies a great part of the larger island; it is less than a fathom deep, and its level does not rise and fall with the tide, while the water it contains is much denser than sea-water *. At the bottom of the lagoon there is a thick layer of black mud, which gives out a strong smell of decomposing matter when it is stirred. The land border is broad on the west and north-west of the lagoon, but narrow on the other sides. A ridge on the western side attains a height of over 160 feet at two points. On the east the land is much lower, varying from 15 to 96 feet above the sea, and on the south-west it is often hardly higher than the top of the beach. The formation consists of coral rock.

Nomuka and Nomuka-iki are surrounded by fringing reefs, which in the case of the latter stretch out a considerable distance (in one part over a mile) from the shore. The twenty-fathom line encloses both islands; on the eastern and north-western sides of Nomuka it is about half a mile from the edge of the reef, while on the west and south-west of Nomuka-iki it is a mile away and encloses some outlying coral patches. Outside the twenty-fathom line the slope is very gradual. Eight miles from land on the west and south-west (the only directions in which distant soundings have been taken) the depth is not greater than 50 fathoms †.

Nomuka is evidently an atoll which has been formed in shallow water, though it is only in the last stage of its elevation that the ring has been completed; and here the shallowness of the surrounding sea appears to exclude subsidence as a factor in its formation: for the summit of the elevation on which, on that hypothesis, the limestone formation rests would lie beneath the lagoon; but the floor of the lagoon is only some 9 fathoms higher than the bottom of the surrounding sea outside the reef.

To the east of the Nomuka Group, a reef dotted with islands is

* On comparing the density of the lagoon-water with that of sea-water and distilled water by means of a hydrometer, the readings were:—

| | |
|---|---|
| Distilled water | − 2 |
| Sea-water | +25 |
| Lagoon-water | +39 |

† Opposite the western end of the channel between the islands I obtained a branch of a living madrepore at a depth of 31 fathoms, and a living fragment of one of the *Poritidæ* came up on the 'Egeria's' sounding-lead from the same depth.

marked on the chart, resembling on a small scale the great Hapai barrier to the north.

Tongatabu is the largest island of the group. It is some 22 miles in greatest length, and of an irregular crescent shape, with its convexity presented to the south. Considerable tracts along the northern shore are not above the reach of the highest tides ; but the level gradually rises towards the convex border, and the highest part is at the south-east, opposite Eua.

An extensive shallow area lies to the north of the island. Opposite the middle of the northern shore, and extending for about a third of the whole of its length, there is a large basin, which forms the harbour of Nukualofa. It has an average depth of 15 fathoms, and communicates with the outer water by a deep channel on the eastern side.

A wide shallow area, having a depth of from 6 to 9 fathoms, extends from the western point of the island eastward, bounding the basin and eastern channel on the north. Along the outer or seaward margin of this area coral reefs grow up to the surface, forming a more or less continuous barrier on the east and north-west. To the north, however, the line of reefs is interrupted, and here shallow banks (though apparently without reefs) extend for some 15 miles in the direction of the Nomuka Group. Several islands, some of sand, some of coral rock elevated about 15 feet, are dotted along the reefs on the north of the harbour and eastern channel.

The interior of Tongatabu is partly occupied by an irregular and shallow lagoon, which communicates with the sea on the north.

Regarding the island and the shallow tract to the north as a whole, we find an area whose circumference, represented by the convex border of the island on the south, and the shallow 9-fathom area, on which reefs have grown, to the north, stands at a higher level than the central part, represented by the lagoon and the 15-fathom basin.

In mentioning this island, Darwin pointed out * that "it resembles either an up-raised atoll, with one half originally imperfect, or one unequally elevated." The gaps in the line of reef along the northern margin show that the atoll was imperfect ; but the gradual rise of the land towards the convex side, and the fact that it attains its highest point where it most nearly approaches the greatly elevated island of Eua, appear to point strongly to the conclusion that it has also been unequally elevated.

The island is formed of coral limestone throughout, and in many places this rock lies at the surface. In the grassy roads of the town of Nukualofa one often meets with flat patches of coral, many feet in diameter, on which the lines of astreids or madrepores are seen radiating from a common centre. Elsewhere the rock is covered with a layer of reddish-brown clay, which in some cases attains many feet in thickness †.

The contour of Tongatabu is flat or presents gentle undulations,

* 'Coral Reefs,' 3rd ed. p. 177.

† A similar clay overlies the limestone formation of Vavau.

but there are no streams or stream-channels on the surface. The rain soaks through the porous rock, and finds its way to the sea by underground channels excavated in the limestone. The caverns and subterranean galleries which have been thus hollowed out by the water are in some places very extensive, and in walking about the island one is often reminded of their presence by the hollow sound of one's footsteps.

Some remarkable features are presented by the narrow reef fringing the southern and eastern shores of Tongatabu. The land gradually slopes towards the ocean, and ends abruptly in a low cliff of coral rock. From the foot of the cliff there extends towards the sea a narrow reef-platform, whose outer edge is raised, forming a barrier * several feet in height. This barrier is in the position of the mound formed of nullipores which is commonly found near the seaward edge of a reef-platform †. It presents a steep surface towards the platform, and a vertical one towards the sea. In many places there is on the platform a depth of five feet or more of water, whose level is above that of the sea, and which is prevented from flowing away by the barrier on the seaward side. The upper surface of the barrier is formed of a number of shallow basins—the upper ones several feet in width—whose rims are perfectly level and which stand at different heights, the lower basins surrounding the upper, stage below stage, strongly recalling the structure which was presented by the well-known pink and white terraces of Lake Rotomahana in New Zealand. The outer part of the barrier is penetrated by fissures which open above by rounded apertures left between the margins of the basins.

The rollers, coming up from the open ocean, break against the steep face presented to them by the reef, and are thrown aloft in clouds of spray, while great jets and spouts of water are forced up through the fissures. The water falls into the basins on the barrier, streaming over their level edges along the whole of their circumference, to be caught by the basins beneath, and so down from basin to basin.

The edges and outer sides of the basins are covered with living nullipores, which grow in encrusting laminæ, and flourish in the freshly aerated water which streams over them. Wherever the water flows, the nullipores grow; and thus the edges of the basins are kept level, and are constantly growing upwards and outwards.

It appears probable that such a barrier is a form of the nullipore mound. Its unusual height and the remarkable basin-like formation may be due to the steepness of the outer slope of the reef, causing the waves which break against it to be thrown upwards, and thus the water in which the nullipores flourish always falls on them from above.

The reef on the eastern shore of Eua presents similar features.

The little island of Eua-iki lying opposite the mouth of the eastern

* This term is used without any reference to a barrier-reef.

† The nullipore mound at Keeling Island is described in Darwin's 'Coral Reefs,' 3rd ed. pp. 13, 14.

channel is composed of a higher central area, separated by a rapid descent from the lower peripheral part. It has evidently been elevated in two stages.

## IV. Conclusion.

The view of the mode of formation of the Tonga atolls suggested in Darwin's 'Coral Reefs,' is that they grew during a period of subsidence, when the volcanoes of the group were inactive, and that elevation has occurred simultaneously with a recent volcanic outbreak *. Dana also considers that the islands were formed during subsidence, and regards the elevation which has taken place as merely a local phenomenon †. The additional information on the group which we now possess appears to make a different view of the formation of these islands more probable. It is clear that elevation has been in progress for a long period, and has been renewed again and again after intervals during which reefs of considerable extent have grown; it has to a greater or less extent affected all the larger divisions of the group, while at Vavau and Eua reef-structures have been raised to heights of over 500 and 1000 feet.

Such an elevatory movement is quite in keeping with the presence of the line of volcanoes which traverses the group, and I am not aware that there is any evidence that these have, as a whole, passed through a quiescent stage previous to their activity in recent times.

With regard to atolls in general, one reason for considering them to have been formed during subsidence is the improbability of there being any other basis than a subsided island on which the reefs could have grown. In the Tonga Islands, however, the soundings of H.M.S. 'Egeria' show that Tongatabu and Nomuka rest on shallow banks, and where the underlying basis of the islands is exposed, as in the Nomuka group and at Eua, it is seen that they consist of layers of volcanic materials laid out under water. The process now going on at Falcon Island illustrates the way in which a volcanic mound, composed of soft material and originally standing above the sea, may be reduced to a submarine bank, and so form a basis for coral growth.

In consideration of these facts it appears probable that the atoll-shaped islands of the southern part of the Tonga Group have grown on banks of volcanic material laid out in shallow water, and that there is no necessity to call in the hypothesis of subsidence to account for their formation.

## EXPLANATION OF PLATE XXIII.

Map of the Tonga Islands. The map of Eua is prepared partly from the survey of H.M.S. 'Egeria' (1888). The outlines of the patches of volcanic formation in the central part of the island are not accurately drawn.

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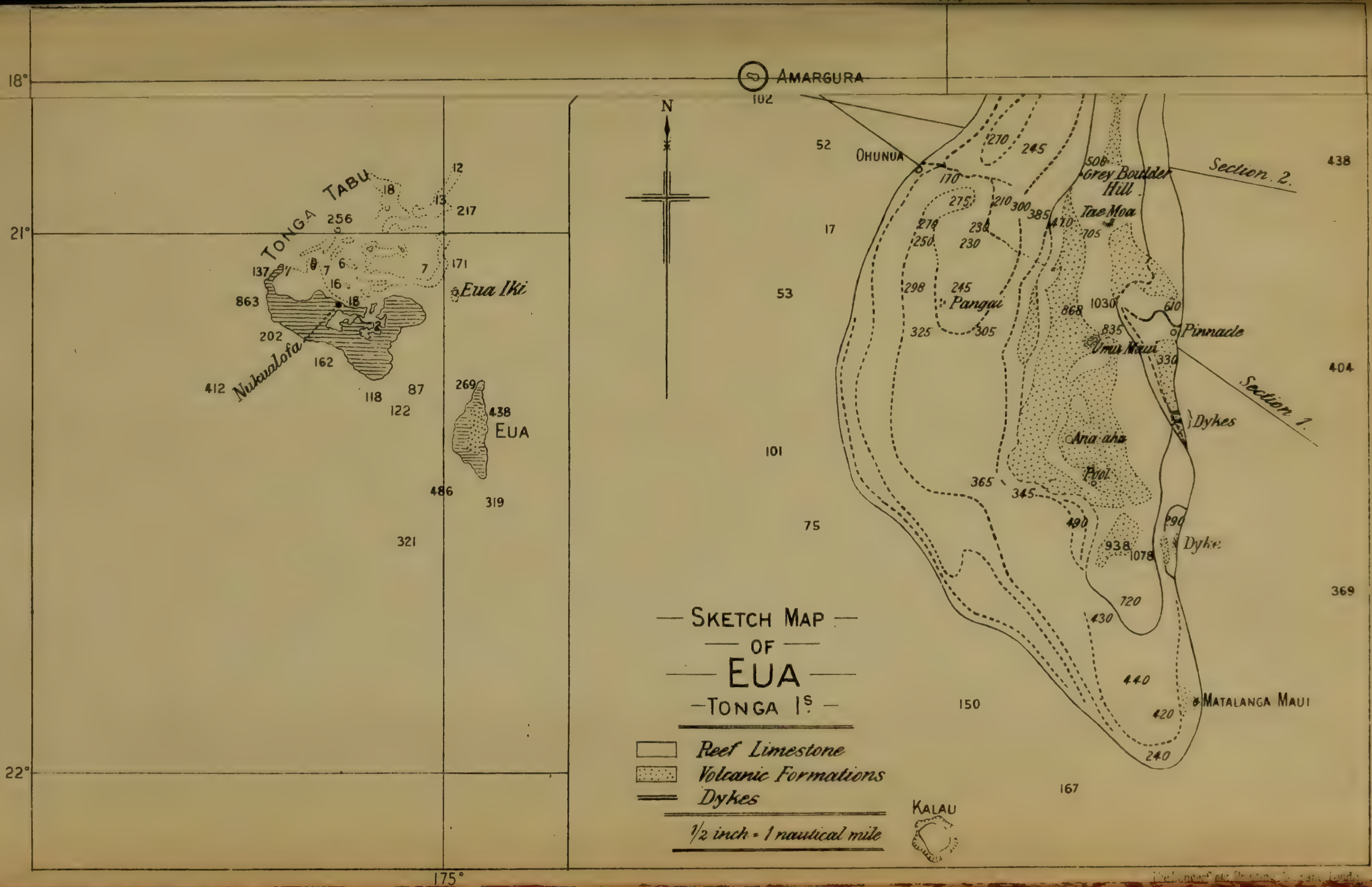
* 'Coral Reefs,' 3rd ed. pp. 177, 186, 188.

† 'Origin of Coral Reefs and Islands,' Am. Journ. Sci. ser. 3, vol. xxx. (1885) p. 99.




— Sketch Map —
— of —
— EUA —
— Tonga Is. —

Reef Limestone
Volcanic Formations
Dykes

½ inch = 1 nautical mile


THE
TONGA OR FRIENDLY I^S.
indicates Volcanoes
" Tuff Islands
" Limestone Form^ns
Amargura
Toku 82 Feet high
Talau
About 500 Feet high
Vavau Group
Mounga Lafa
Hunga
Neiafu
Aa
Lette I^d 1890 Feet high
Metis I^d 151 Feet high
Kao I^d 3030 Feet high
Tofua I^d 1890 Feet high
Fotuha
Kotu I^s
Kotu
Haleva
Matuku
Haano
Foa
Lefuka
Uiha
Alefu
Oua
Hapai Group
Falcon I^d 153 Feet high
Nomuka
Nomuka Iki
Tonua
Mango
Nomuka I^s
Tonumeia
Kelefesia
Honga Hapai 200 Feet high
Honga Tonga 300 Feet high
Tonga Tabu
Nukualofa
Eua Iki
Eua
Sketch Map of Eua
Tonga I^s
Reef Limestone
Volcanic Formations
Dykes
1/2 inch = 1 nautical mile
Ohunua
Houma
Grey Boulder Hill
Tao Moa
Pangai
Pinnacle
Umu Maui
Section 2
Section 1
Dykes
Ana ahu
Pool
Dyke
Matalanga Maui
Kalau
18°
19°
20°
21°
22°
174°
175°

## Discussion.

Mr. Hickson said that Mr. Lister's researches on the coral reefs of the Friendly Islands were of great interest and importance, as they supported the view that atolls and barriers may be formed in regions of elevation, and that the "subsidence theory" is not sufficient to account for all the phenomena that occur in volcanic regions. The Tonga and Kermadec groups of islands are very similar to the chain of islands that stretches from the northern peninsula of Celebes to the southern promontory of Mindanao. Here we find a chain of volcanoes, many of them active at the present day, represented by the Ruang, the Siauw, and the Awu, with broad barrier-reefs and ring-shaped atolls in their immediate vicinity. The researches of Sluiter in the Java seas prove that coral islands and reefs are frequently formed on a substratum of soft clay and mud.

Mr. J. W. Gregory remarked on the great value of Mr. Lister's paper, and the interest attaching to the discovery of a plutonic rock on the islands. Taken in conjunction with the discovery of similar rocks in the Marquesas, and the presence there of genera otherwise restricted to South America and Malaysia, it helped to afford an explanation of some difficult problems of distribution. Manganese nodules seem characteristic of deep-sea conditions, not only at present, but in earlier periods; thus in the Maltese Miocenes they are associated with a fauna of about 1000 fathoms. Their occurrence, therefore, proves considerable elevation, and it is not surprising that the coral limestone occurs as thin crusts; the Tongas thus afford only another case of coral formation in shallow or rising areas, for which, as Darwin has so emphatically insisted, his theory was not proposed.

Mr. Goodchild enquired whether the boulder of gabbro referred to might not have reached its present level as an ejected block; this view might serve to explain the occurrence of plutonic rocks in an oceanic island.

# 36. *On the* Inverness Earthquakes *of* November 15 to December 14, 1890. By Charles Davison, Esq., M.A. (Read June 24, 1891.)

[Communicated by Prof. C. Lapworth, LL.D., F.R.S., F.G.S.]

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## I. Introduction.

The earthquakes felt towards the close of last year in the district round Inverness form an interesting chapter in the recent physical history of Great Britain. Fortunately, the first undoubted shock was the most severe one, and this drew the attention of numerous observers to the slighter, but not less important, earthquakes which succeeded it. In some respects the evidence is incomplete, owing to the early hour at which many of the shocks occurred; but it is on the whole full enough to indicate in outline the succession of events and their relation to the geological structure of the district.

In studying these earthquakes the accounts given in the local newspapers have been found of some service, but I have chiefly relied on records sent to me in reply to a series of questions which were circulated as widely as possible throughout and near the disturbed area. At the end of this paper I have acknowledged in detail the help thus received; but I wish here to offer my hearty thanks to those who have assisted me—first, for the valuable information which they have placed at my disposal, without which this paper could not have been attempted, but not less for the unfailing courtesy and kindness with which my enquiries have been received.

During the period mentioned at least eleven undoubted shocks were felt. Besides these, there were nine others, each depending on the evidence of one witness only, but they were noticed and

recorded by observers who paid such close attention to the earthquakes that their evidence is, I believe, sufficient to attest their seismic origin. I have, however, thought it best not to depart from the excellent rule laid down by the Swiss Seismological Commission, and have inserted these under the heading of "Doubtful Shocks" instead of in their proper chronological order.

In the following accounts the time of occurrence is given in Greenwich mean time, the hours being numbered from 0 to 24, but it is necessary to remark that for several reasons the times here recorded can at best be regarded as approximations only. The intensity is estimated by means of the Rossi-Forel scale. In considering the position of the seismic focus and of the epicentrum I refer, for this purpose only, to its centre of intensity for the former, and to the point vertically above it on the earth's surface for the latter. Following the notation of M. Forel, I have divided the shocks into *principal* and *accessory*. These are denoted by capital and small letters respectively.

## II. Principal Shock, A: Nov. 15, $17^h$ $50^m$.

Intensity.—VII.
Epicentrum.—Lat. 57° 25′ 0″ N., long. 4° 10′ 50″ W., *i. e.* 4½ miles S. 21° E. of Inverness.

Of this earthquake, the most intense of the series, I have 160 records from 115 different places. For the observations at eleven of these I am obliged to trust to newspaper accounts alone. The rest are given in the form of replies to my printed questions, and in nearly every case are carefully made and possess a high value.

1. *Disturbed Area.*—The map accompanying this paper refers principally to this earthquake. On it are marked, with very few exceptions, all the places where the shock was felt. These are indicated by small discs. Places where earthquake-sounds were heard at the same time are denoted by crosses (+), drawn through the discs when the shock was also felt, or separately if the shock passed unperceived. The two continuous lines are isoseismal lines of intensities V. and IV. respectively; the dotted lines represent the boundaries of the disturbed areas of three of the subsequent shocks. (See next page.)

Outside the isoseismal of intensity IV. I have records from only 16 places, and these are not sufficient to determine exactly the boundary of the disturbed area. Except towards the north, however, none of these places is more than ten miles from the isoseismal. At Helmsdale there is an increase of intensity, and I am by no means certain that this was not caused by a separate, but perhaps not independent, earthquake.

The area disturbed by the earthquake within the isoseismal of intensity IV. is 86½ miles long and 61½ miles broad, the longer axis being directed N. 52° E. and S. 52° W. The area contained by this curve is about 4340 square miles, including the part covered by the sea.


MAP
showing the localities
AFFECTED BY THE
INVERNESS EARTHQUAKES
of
Nov.15 to Dec.14, 1890.
0 5 10 15 20
SCALE OF MILES.
A. Isoseismal IV.
A. Isoseismal V.
LINE OF SUPPOSED FAULT
BRAEMORE
DUNBEATH CA.
KILDONAN
NAVIDALE
HELMSDALE
LOTH
LAIRG
TRESSADY
ROGART
GOLSPIE
INVERSHIN
CULRAIN
BONAR BRIDGE
ARDGAY
DORNOCH
INVERGORDON
ALNESS
NIGG
CROMARTY
EVANTON
FOWLIS
AULTGUISH INN
ACHANALT
GARVE
GLENCARRON
STRATHPEFFER
DINGWALL
MARYBURGH
BRAHAN CA.
CONON
FAIRBURN
REDCASTLE
KILMUIR
KESSOCK
FORTROSE
CHANONRY PT.
AVOCH
F. GEORGE STA.
NAIRN
CAWDOR
URRAY
BEAULY
KIRKHILL
CLUNES
INVERNESS
BALNAFETTACK
BUNCHREW
CLACHNAHARRY
TORBRECK
DAVIOT
ALDOURIE
DORES
MOY
MOYHALL
FREEBURN INN
STRUY
INCHBREEN
DRUMNADROCHIT
BRIN
CORRIMONY
BUNCHRUBIN
TORNESS
DALAROSSIE
DELRACHNIE
ERROGIE
DUNMAGLASS
BOLESKINE
INVERMORISTON
GLOMACH
ABERNETHY
AVIEMORE
KINGUSSIE
NEWTONMORE
LOCH HOURN HEAD
GLENQUOICH
INVERGARRY
FEDDAN
ACHNACARRY
BURGHEAD
HOPEMAN
COVESEA
LOSSIEMOUTH
DUFFUS
NEW SPYNIE
ELGIN
KINLOSS
FORRES
DYKE
AULDEARN
RAFFORD
DUMPHAIL CA.
EDENKILLIE
FOCHABERS
BOHARM
KEITH
DALMUNACK
GLASS
BEN RINNES
DAVA
CROMDALE
DUTHIL
KIRKMICHAEL
BRUIN BR.
MINTERN BROS.

2. *Nature of the Shock.*—The nature of the shock varied considerably throughout the disturbed area, this variation being of course a necessary consequence of the position and magnitude of the seismic focus. I will first give a few descriptions in detail out of a large number received.

Beauly : A heavy rumbling sound was heard before and during the shock. Three distinct vibrations were first felt, more intense to begin with, and were followed by a tremulous motion; the whole lasting about 8 or 10 seconds. The vertical motion was very perceptible, first upward and then downward.

Dingwall : A heavy rumbling sound was first heard, followed by a violent quivering of the ground, consisting of about 10 or 12 vibrations, first increasing in intensity and then gradually dying away. The duration of the shock, excluding that of the sound, was 5 seconds.

Drumnadrochit : "First a tremulous shake, then four strong vibrations, and again a tremulous shake. I would say four weak, four strong, and again four weak vibrations. With the last shake of the strong vibrations there was a distinct heave. A very loud sound accompanied the shock, becoming louder the greater the vibration, but ending more abruptly than the quiver." The duration of the shock alone was 6 seconds.

Glen Urquhart (at the schoolhouse): "It began with a noise like the distant sound of cannon, which grew louder and louder, and a tremor of the ground, at first slight, but which rapidly increased in violence, and culminated in a quick lurching motion of the floor. Both sound and motion then died away as they grew."

These accounts will show sufficiently the nature of the shock; and I will now give a brief summary of the others.

The intensity of the vibrations was greatest near the beginning at Beauly and Invermoriston, about the middle at Dingwall, Dores, Drumnadrochit, Glen Urquhart (the schoolhouse), and Inverness, and towards the end at Fowlis station and Invergordon.

In most cases the observations are not sufficiently detailed to determine any law in the distribution of places according to the duration of the shock or the number of vibrations felt. For the most part, however, prominent and well-marked vibrations were felt only in the neighbourhood of the epicentrum, these being often preceded and followed by tremors; and towards the boundary of the disturbed area the shock was only perceptible as a faint tremulous motion.

At the following places the motion was distinctly felt to be partly vertical:—Aldourie, Beauly, Bunchrew, Bunchrubin, Cawdor, Clunes station, Conon, Delrachnie, Dingwall, Dores, Dyke, Fortrose, Invermoriston, Inverness, Moy, Rafford, Redcastle, and Torbreck. It will be noticed that none of these places is at a greater distance than twenty-five miles from the epicentrum. At places more distant than this the direction of the motion, when referred to, is always described as horizontal.

The vertical motion was first upward and then downward at

Aldourie, Beauly, Bunchrubin, Cawdor, Dingwall, Inverness, and Torbreck; first downward and then upward at Dyke.

3. *Intensity.*—At a few places the shock was strong enough to produce slight damage to buildings. At Inverness, in the south-east part of the town, a chimney was thrown down, and in the east part a house-wall was cracked. Between Dores and Inverness a wall was cracked. At Clunes the shock was strong enough to "open cracks" in the walls. At Beauly the only damage known was the fall of a chimney-can. It is obvious that damage of so slight a character does not entitle us to rank the intensity of the shock at more than VII., according to the Rossi-Forel scale. The following table gives the intensity at different places, as far as known to me:—

VII. Balnafettack, Beauly, Clunes station, Dingwall, Drumnadrochit, Inverness, Kirkhill, North Kessock.

VI. Aldourie, Fortrose.

V. Boleskine, Chanonry Point lighthouse, Conon, Cromarty Ferry (near Nigg), Delrachnie, Dores, Dunmaglass, Dyke, Edenkillie, Fort George station, Glassburn, Invermoriston, Moy, Nairn, Strathpeffer, Torbreck, Torness.

IV. Alness, Auldearn, Aultguish Inn, Avoch, Bunchrubin, Burghead, Covesea lighthouse, Cromdale, Dalmunack, Dunrobin Glen, Forres, Garve, Glass, Glencarron, Glomach, Golspie, Helmsdale, Inchbreen, Kinloss, Kirkmichael, New Spynie, Newtonmore, Rafford, Struy.

III. Achnacarry, Duffus, Hopeman, Keith, Kingussie.

The data are sufficient to allow isoseismal lines corresponding to intensities V. and IV. to be drawn. The former is 48 miles long and 37 miles broad, and includes an area of about 1350 square miles; its longer axis is directed from N. 48° E. to S. 48° W. The dimensions of the latter curve have already been given. The longer axes of the two curves are therefore approximately parallel. It is also noteworthy that in the north-west quarter the distance between the isoseismals is 17 miles, *i. e.* more than twice as great as towards the south-east, where it is $7\frac{1}{2}$ miles.

The centre of the isoseismal line of intensity V. is at a point $4\frac{1}{2}$ miles S. 21° E. of Inverness. This point may be taken as indicating the position of the epicentrum, the distance between the two points in all probability being very small.

4. *Sound-phenomena.*—I have received records altogether from 115 places; in 95 of these the usual earthquake-sounds were heard; in two of them the sound was heard, but the shock was not noticed; from the remaining 18 places no reference is made to sound-phenomena. As already stated, the places where the sound was heard are indicated by small crosses (+) through the spots representing them; and a glance at the map is sufficient to show that, so far as the evidence goes, the earthquake-sounds were heard throughout the whole of the disturbed area.

In its nature the sound does not seem to have differed in any way from those usually heard during British earthquakes. Detailed description is therefore unnecessary.

When variations in intensity are noticed, the sound generally began faintly, grew gradually louder to a maximum, and then died gradually away. This was the case at Abernethy, Alness, Ardgay, Boleskine, Cawdor, Corrimony, Delrachnie, Drumnadrochit, Duthil, Errogie, Evanton, Glassburn, Glen Urquhart (the schoolhouse), Kilmuir, Kingussie, and Urray. It will be noticed that, as a rule, these places are at no great distance from the epicentrum. At Aldourie and Invermoriston the sound, when first noticed, was at its maximum intensity, and died away gradually. At Rafford the sound ended suddenly; and at Lairg it ended suddenly, almost simultaneously with the principal shock.

The principal vibrations were felt when the sound was loudest at Aldourie, Boleskine, Delrachnie, Drumnadrochit, Evanton, Glassburn, Glen Urquhart (the schoolhouse), Invermoriston, and Kilmuir.

5. *Time-relations of the Shock and Sound.*—The sound is said to have:

Preceded the shock at 20 places: Auldearn, Avoch, Badenoch, Boharm, Boleskine, Cawdor, Chanonry Point lighthouse, Dalmunack (near Carron station, Banffshire), Dingwall, Duffus, Dunain Hill ($2\frac{1}{2}$ miles S.W. of Inverness), Dyke, Elgin, Feddan, Lairg, Marybuirgh, New Spynie, Newtonmore, Nigg (at Cromarty Ferry), and Struy.

Accompanied the shock at 26 places: Achnacarry, Alehousehillock (near Cairney), Aldourie, Alness, Balnafettack, Braemore, Burghead, Cromarty lighthouse, Daviot, Dornoch, Drumnadrochit, Dunrobin Glen (near Golspie), Edenkillie, Fort George station, Golspie, Golspie Burn, Helmsdale, Kildonan, Kilmuir, Kingussie, Loth, Moy, Rafford, Strathpeffer, Torness, and Tressady.

Followed the shock at one place: Clunes station.

Preceded and accompanied the shock at 5 places: Beauly, Fortrose, Glassburn, Inverness, and Nairn.

Accompanied and followed the shock at 5 places: Ardgay, Bunchrubin, Dores, Invermoriston, and Torbreck.

Preceded, accompanied, and followed the shock at 7 places: Brin, Bunchrew, Cromdale, Delrachnie, Evanton, Invergordon, and Kirkmichael.

The terms "preceded," "accompanied," and "followed," singly, are vague, and the numbers under these headings would probably have to be distributed under the last three if these descriptions had been more detailed: and this indefiniteness is, I regret, owing to the fact that the question on this point was not worded with sufficient exactness. But the observations above recorded are not without their value. If reference be made to the map (p. 620) it will be found that the twenty-five places at which the sound preceded, or preceded and accompanied, the shock, though not confined to any one part of the disturbed area, are mostly situated in the district

north-east of the epicentrum; and the six places at which the sound followed, or accompanied and followed, the shock are, with the exception of Ardgay, either south-west of the epicentrum or close to it on the north-west side, *i. e.* just where the intensity is greatest.

## III. Accessory Shocks.

### b. *Nov.* 15, $18^{h}\ 15^{m}$.

Intensity.—IV.
Epicentrum.—Lat. 57° 26′ 20″ N., long. 4° 15′ 20″ W., *i. e.* 3 miles S. 24° W. of Inverness.

The shock was felt at the following places: Aldourie, Balnafettack, Beauly, Blackpool of Muistoun (near Inverness), Bunchrew, Clachnaharry, Clunes station, Dores, Drumnadrochit, Fortrose, Glen Urquhart (the schoolhouse), Inchbreen, Inverness, Kilmuir, Moyhall, Redcastle, Torbreck, and Torness. The earthquake-sound was heard at: Balnafettack, Blackpool of Muistoun, Clunes station, Drumnadrochit, Inchbreen, and Kilmuir; it was also heard at Brin and Invermoriston, but at these places the shock was not felt. At Fortrose and Inverness, places where the shock was felt, the sound was not heard.

The disturbed area is $25\frac{1}{2}$ miles long and $18\frac{1}{2}$ miles broad, and contains about 370 square miles. The longer axis is directed N. 47° E. and S. 47° W. The centre of the area is at a point 3 miles S. 24° W. of Inverness.

The intensity was IV. at Balnafettack, Inverness, and Torbreck, all of them places very near the epicentrum. It was decidedly less than IV. at Aldourie, Clunes station, Dores, Fortrose, and Inchbreen, these being places at a greater distance from the epicentrum. The boundary of the disturbed area is therefore an isoseismal of intensity less than IV., and perhaps not much more than III.

As to the nature of the shock I know very little. At Inverness the motion was similar to that caused by the first shock, but of much less intensity; the vertical component of the motion was well marked, and it was upward first and then downward. At Clunes station it was a swaying motion, followed by a trembling. At Glen Urquhart and Beauly only a slight tremor was perceived. The duration of the shock is given at 2 seconds near Inverness and 3 seconds at Clachnaharry.

### c. *Nov.* 16, $9^{h}\ 15^{m}$.

Intensity.—IV.

The shock was felt at: Aldourie, Balnafettack, Boleskine, Bunchrew, Cawdor, Clachnaharry, Clunes station, Dores, Inverness, Moy, and Torbreck. The earthquake-sound was heard at Balnafettack, Clachnaharry, and Dores, but not at Aldourie, Clunes station, and Torbreck. At Brin the sound was heard, but the shock was not felt.

The information is too scanty to enable the boundary of the dis-

turbed area to be drawn or the position of the epicentrum determined. It will be noticed that two places, Boleskine and Cawdor, are widely separated from the rest. Judging from the data in our possession, however, we may possibly infer that the epicentrum was not very distant from a point $3\frac{1}{2}$ miles S. 20° W. of Inverness.

I know nothing as to the nature of this shock. Its intensity was IV. at Balnafettack, a place probably close to the epicentrum. At Clachnaharry its duration was 3 seconds.

### d. *Nov.* 16, $20^h$ $30^m$.

Intensity.—V.

Epicentrum.—Lat. 57° 26′ 10″ N., long. 4° 19′ 10″ W., *i. e.* 5 miles W. 39° S. of Inverness.

The information respecting this shock is more abundant. I have 37 records from 21 places. The shock was felt at the following places: Aldourie, Balnafettack, Beauly, Boleskine, Bunchrew, Cawdor, Clachnaharry, Clunes station, Dingwall, Dores, Drumnadrochit, Fortrose, Fowlis station, Inchbreen, Inverness, Kilmuir, Strathpeffer, and Torbreck. The earthquake-sound was heard at: Aldourie, Balnafettack, Clachnaharry, Clunes station, Dores, Fowlis station, Inchbreen, Inverness, Kilmuir, and Torbreck, but not at Fortrose. The sound was heard, but the shock not felt, at Brin, Errogie, and Invermoriston.

The disturbed area is 41 miles long, $27\frac{1}{2}$ miles broad, and contains about 910 square-miles. Its longer axis is directed from N. 38° E. to S. 38° W.; its centre is about 5 miles W. 39° S. of Inverness.

The intensity was V. at Clunes station and Torbreck, at least IV. at Inchbreen and Inverness, and less than IV. at Aldourie and Fortrose. The intensity at the boundary of the disturbed area was probably about III.

At Clunes station there was a swaying motion of the floor, followed by a violent trembling. The shock was of an undulating nature at Beauly, the sharp jerking motion of the principal earthquake being absent. In other parts of the disturbed area, where the nature of the shock is recorded, only a slight tremor was perceptible. The duration of the shock was 2 or 3 seconds at Clachnaharry and 3 or 4 seconds at Beauly.

### e. *Nov.* 18, $2^h$ $20^m$.

I have received only one record of this shock—from Mr. D. D. Macdonald, of Drumnadrochit. He says that it was felt by several people at this place, and that there can be no doubt as to its occurrence. It resembled the shock of Nov. 16 at $20^h$ $30^m$.

### f. *Nov.* 19, $1^h$ $40^m$.

So far as I can learn, this shock was felt only at Inverness; it was not noticed at Clachnaharry or Clunes station. The motion

was more vertical than horizontal. One observer seemed to be "jerked upwards by a quick, steady staccato movement," which lasted for a minute or two. The epicentrum, therefore, cannot have been far from Inverness.

g. *Nov.* 19, $2^{h}$ $10^{m}$.

The shock was felt at Inverness and Torbreck; at the latter place it was accompanied by a slight noise. The epicentrum cannot have been far from Inverness, and was probably to the southwest of it.

h. *Nov.* 19, $4^{h}$ $10^{m}$.

Intensity.—IV.

The shock was felt at: Balnafettack, Clachnaharry, Clunes station, Inverness, Torbreck; and, I am informed, at other places in the Ness valley. It was accompanied by sound at Balnafettack, Clachnaharry, and Torbreck; but no sound was heard at Clunes station. The intensity was IV. at Balnafettack and Clachnaharry, and less than IV. at Clunes station. The epicentrum was probably not far from Inverness.

i. *Dec.* 1, $0^{h}$ $15^{m}$.

Intensity.—IV.

The shock was felt at: Aldourie, Balnafettack, Bunchrew, Clunes station, and Inverness. It was accompanied by sound at Inverness. At this place the intensity was IV.; the movement was less vertical than in the previous shocks, being only a gentle swaying.

j. *Dec.* 8, $4^{h}$ $10^{m}$.

Intensity.—V.

The shock was felt at: Aldourie, Balnafettack, Bunchrew, Clunes station, Dores, and Inverness. It was accompanied by sound at Balnafettack, Bunchrew, Clunes station, and Dores; at Inverness the sound was not noticed. The intensity was V. at Balnafettack, IV. at Dores, and less than IV. at Clunes station. The epicentrum was probably near Balnafettack.

## IV. Principal Shock, K: Dec. 14, $3^{h}$ $30^{m}$.

Intensity.—VI.
Epicentrum.—Lat. 57° 26′ 0″ N., long. 4° 17′ 0″ W., *i.e.* 4 miles S. 34° W. of Inverness.

1. *Disturbed Area.*—With the exception of the first shock, this was the strongest of the whole series, but, occurring at an early hour, its apparent disturbed area is somewhat less than that of the fourth shock—that of Nov. 16 at $20^{h}$ $30^{m}$. I have received 20

accounts from 12 different places, but several of these accounts are detailed and of great value.

The shock was felt at the following places:—Aldourie, Balnafettack, Beauly, Boleskine, Brin, Bunchrew, Cawdor, Clunes, Dingwall, Dores, Inchbreen, and Inverness. It is said not to have been felt at Delrachnie, Duthil, Forres, Fort George station, Fowlis station, and Kingussie, but this may have been owing to the early hour of occurrence.

The disturbed area is thus 38 miles long, 27 miles broad, and contains about 820 square miles; the longer axis is about N. 42° E. and S. 42° W.; the centre 4 miles S. 34° W. of Inverness.

2. *Nature of the Shock.*—This shock was distinguished from that of Nov. 15 by its sharpness and short duration. It lasted about 3 seconds at Inverness and Balnafettack, and about 2 seconds at Dores. The following accounts will best describe its nature:—

Dores: one principal vibration, mainly vertical, first upward and then downward, preceded and followed by vibrations that did not admit of being counted.

Inverness: the motion was more vertical than in any of the preceding shocks; there was a sharp and sudden upheaval, and then the earth vibrated violently, but this succeeding tremor was not so violent as that which succeeded the shock of Nov. 15.

The vertical component of the motion was very perceptible at: Aldourie, Balnafettack, Dores, and Inverness; and at all these places it was upward first and then downward.

3. *Intensity.*—The intensity of the shock was VI. at Balnafettack, V. at Aldourie and Dores, and not less than IV. at Beauly, Clunes station, and Inchbreen.

4. *Sound-phenomena.*—At all the twelve places mentioned, except Boleskine and Cawdor, the sound is recorded as having been heard. The sound-area was therefore probably coextensive with the disturbed area. At Balnafettack and Dores the vibrations were felt when the sound was loudest. At Brin and Inverness the sound preceded, accompanied, and followed the shock; at Bunchrew it was heard before, but not after, the shock, all the other shocks at the latter place having been both preceded and followed by sound.

## V. Doubtful Shocks.

Nov. 15, $18^h\ 25^m$, Clunes station. A shock similar to that felt at $18^h\ 15^m$.

Nov. 17, Inverness. A shock felt shortly after midnight.

Nov. 17, $4^h\ 20^m$, Inverness. Three vibrations felt, but no sound heard.

Nov. 17, $4^h\ 30^m$, Inverness. Two vibrations, each accompanied by a sharp report.

Nov. 19, $21^h\ 35^m$, Inverness. A slight tremor.

Dec. 1, about $3^h$, Bunchrew. A slight shock.

Dec. 3, $2^h\ 45^m$, Bunchrew. A slight shock.

Dec. 6, $9^h\ 7^m$, Clachnaharry. No perceptible motion; a noise

heard like the report of a distant cannon, lasting between 2 and 3 seconds.

Dec. 12, $23^h$ $20^m$, Bunchrew. A slight shock.

## VI. Origin of the Earthquakes.

One of the most important faults in the British Isles is that which, following the line of the Great Glen, runs along the base of the cliffs of the Black Isle and the east coast of Ross-shire to Tarbat Ness. Its direction is about N. 35° E. and S. 35° W., its downthrow to the south-east.

Earthquakes are of frequent occurrence along the line of this fault. At Inverness especially, along the course of the Ness valley and at Dores, many have been felt during the present century. Slight shocks are numerous at Invergarry, and in the neighbourhood of Fort William they are not uncommon. The positions of their epicentra and the directions of the longer axes of their disturbed areas suggest that some connexion may exist between the recent earthquake and this important fault.

1. *Principal Shock of Nov.* 15.—Whatever may have been the case with the subsequent shocks, I think, however, that it is impossible, in face of the evidence already recorded in this paper, to admit such a connexion in the case of the principal earthquake of Nov. 15 *. At the same time, I believe that the evidence at our disposal is quite sufficient to enable us to indicate, roughly no doubt, the position of the fault, to slipping along which this earthquake was most probably due. Had a fault in the position assigned been known to geologists, we might have felt considerable confidence in the accuracy of the result arrived at. As it is, we must wait for further research to verify or correct it; but I can interpret the evidence in no other way.

The relative position of the two isoseismal lines of intensities V. and IV. has an important bearing on the problem. We have seen that these lines are much closer together on the south-east than on the north-west side; and this is probably not accidental, for the rocks are of fairly similar constitution for some distance on both sides of the Great Glen. Now, if the earthquake originated in a fault, the intensity of the shock would be greatest, and its duration least, not far from the point where the perpendicular to the fault-plane through the seismic focus meets the surface of the earth, *i. e.*

* The reasons for rejecting the theory of a connexion between this earthquake and the great fault are briefly :—

1. Six out of the eight places where the intensity was greatest (VII.) lie on the N.E. or upthrow side of the fault, and the other two places (Balnafettack and Inverness) are close to the line of fault.

2. The two isoseismals are farther apart on the N.W. than on the S.E. side, which is inconsistent with a south-easterly hade.

3. The places where the movement was upward first and then downward occur on both sides of the line of fault.

4. The distribution of the places where the sound followed, or accompanied and followed, the shock favours a north-westerly hade.

on the downthrow side; and, on this side, the intensity will diminish less rapidly than on the upthrow side of the fault *. It follows, therefore, that on the side towards which the fault hades two given isoseismal lines must be farther apart than on the opposite side, and, consequently, that the fault in question must hade to the north-west.

Now, if the mass of rock on the north-west side were to slip slightly downward relatively to that on the other side, the particles on the north-west rock-face would be drawn upward by the friction, and those on the south-east rock-face downward. Hence, on the north-west side, wherever the vertical component of the motion is appreciable, the movement should be first upward and then downward; on the south-east side it should be first downward and then upward. Now, the movement, we have seen, was upward first at Aldourie, Beauly, Bunchrubin, Cawdor, Dingwall, Inverness, and Torbreck, and it was downward first at Dyke. The line in which the fault meets the surface must therefore pass between Cawdor and Dyke and south-east of Bunchrubin. Bearing in mind also the direction of the longer axis of the disturbed area (about N. 50° E. and S. 50° W.) and the position of the epicentrum, it is evident that the fault-line must pass through a point 6 miles S.E. of Inverness. and, when produced, must meet the west shore-line of Loch Ness at a point 5 miles from its southern extremity. The suggested fault, if it exist, would appear to be a branch of the great fault which occupies the course of the Great Glen †.

I have carefully examined all the evidence at my disposal, and I know of nothing opposed to this view of the origin of the earthquake. On the other hand, it is supported by two other phenomena: (1) the fact that all the eight places where the intensity was greatest (VII.) lie on the north-west or downthrow side of the suggested fault, and (2) that three places (Clunes station, Dores, and Torbreck) at which the sound was heard after the shock cannot be far from the point where the perpendicular to the fault-plane through the focus meets the surface, and at this point the shock would be felt before any sound was heard. Also, the angle between the lines of the branch fault and of the great fault is about 15°, which is not far from the usual angle in such cases; further, the direction of the branch fault is approximately parallel to the main line of folding in the district, and this, again, is in accordance with a known geological law. It is clear we cannot regard the existence of this branch fault as actually proved, but possibly many a fault has been laid down upon a geological map on less satisfactory evidence.

* This statement is not true in all cases; the limits within which it is applicable will be considered in a subsequent paper.

† The line of the branch fault, as I have drawn it, is approximately parallel to the southern boundary of the Old Red Sandstone in the neighbourhood of Inverness, but about a mile to the south-east of it, as shown in Geikie's Geological Map of Scotland. There can be no direct connexion between the two, for there can be no doubt whatever, Mr. Horne informs me, that in this part, at any rate, 'the junction of the Old Red Sandstone is not a fault, but an unconformability.'

Taking into account the long duration of the shock (at some places as much as 30 seconds) and the elongated form of both isoseismal lines, especially that of intensity V., it is probable that the seismic focus was of considerable length in a horizontal direction, perhaps as much as four or five miles, if not more. Since the intensity of the principal vibrations was greatest towards the beginning in the neighbourhood of the south-west end of the focus, and since a large number of the places where the sound preceded the shock are grouped about the continuation of the fault-line towards the north-east, we may infer that the amount of the fault-slip was greatest near the south-west end of the focus, and died out more gradually towards the north-east end. This is what we should expect, the junction of the branch fault with the main fault being to the south-west of the epicentrum.

2. *Subsequent Shocks.*—Turning now to the later shocks, we have the epicentra of three of the most important determined. Referring to the map (p. 620), it will be seen that these three points (*b*, *d*, K) lie on the south-east side of the main fault, but much nearer to it than to the branch fault. The epicentra of the other accessory shocks cannot be exactly ascertained, but it is obvious, from the positions of the places at which they were felt, that, if connected with either, they are more closely related to the main than to the branch fault.

In the first accessory shock (*b*, Nov. 15, $18^h\ 15^m$), the vertical component of the motion at Inverness was upward first and then downward. This was also the case in the sixth shock (*f*, Nov. 19, $1^h\ 40^m$) at Inverness, and, again, in the last shock of all (K, Dec. 14) at Aldourie, Balnafettack, Dores, and Inverness—all places to the south-east of the line of the main fault. At Inverness, also, it was noticed that the direction of motion of the last shock was more nearly vertical than in any of the preceding shocks.

In these three shocks at least, then, the fault-slip must have been such that the rock-mass on the south-east side slipped downward relatively to the rock-mass on the north-west side. Judging from the positions of their epicentra, we infer that the depth of the seismic focus of the first accessory shock (*b*) was greater than that of the last shock (K), and the depth of the seismic focus of this, again, greater than that of the third accessory shock (*d*).

3. *Conclusion.*—The main fault and the branch fault include between them a great wedge of rock, capped for the most part by a mass of Old Red Sandstone, and tapering off towards the south-west. Now, it is more likely that this wedge should subside as a whole than that it should remain fixed while the great rock-masses on either side of it are both elevated at practically the same time. The positions of three known epicentra (*b*, *d*, and K), almost opposite to that of the principal epicentrum (A), are also in favour of the former view. I conclude, then, that the earthquakes were caused by slight interrupted subsidences of this wedge of rock; that the first, and at the same time the greatest, slip took place along the branch fault, though it may possibly have been preceded by a few

slips so slight in extent, and therefore so short in period, that the vibrations produced by them were perceptible only as earthquake-sounds *. The strain, being thus relieved along the branch fault, was in consequence immediately increased along the main fault; and, within half an hour, the strain there was relieved, but only partially, and for nearly another month the relief was at intervals continued by slight slips, varying both in surface-position and in depth, the last slip of all being the most important which took place along the main fault.

"It is by no means impossible," says Prof. Lapworth in concluding his well-known paper on 'The Secret of the Highlands,' "that the long straight . . . . and so-called *anticlinal* valleys of the Scottish Highlands, such as those of the Great Glen and Loch Tay, walled in by steep hill-slopes and occupied by lakes of profound depth, are nothing more than greatly depressed intermont *synclinal troughs*, owing their origin to the same causes which bring about the slow secular elevation and approximation of their flanking ranges " †. It will be obvious that, so far as regards the Great Glen, the conclusions arrived at in this paper are in close accordance with the above suggestion; but, whatever view may be held on this subject, there can be little doubt that the recent earthquakes of Inverness were the transitory records of changes that, by almost indefinite repetition in long past time, have resulted in the great Highland faults.

## VII. Authorities.

Some of the facts recorded in this paper are taken from the accounts published in two local newspapers, the 'Inverness Courier' for Nov. 18, 21, and Dec. 16, and the 'Northern Chronicle' for Nov. 19, Dec. 3 and 17.

But for by far the greater and more valuable part I am indebted to the kindness of numerous ladies and gentlemen who answered my enquiries either addressed to them personally or contained in letters published in the newspapers above mentioned. The following list contains the names of my correspondents, with the exception of a few who have expressed a wish that their names should be withheld:—

Abernethy, Rev. W. Forsyth, D.D.; Achanalt, Mr. J. Taylor; Achnacarry, Mr. W. Sharp; Alehousehillock (Cairney), Rev. A. Fiddes, B.D.; Aldourie, Mr. J. Donald; Alness, Rev. W. L. Wallace Brown; Ardgay, Mr. W. T. Brown; Auldearn, Rev. J. Bonallo; Aultguish Inn, Mr. D. Mackay; Aviemore, Mr. J. S. Lawrence; Avoch, Rev. J. Gibson; Balnafettack, Mr. J. Birnie; Beauly,

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* On the following occasions sounds, possibly seismic, were heard and recorded by a single observer:—

Nov. 12, about $1^h$, Inverness. A rolling noise heard.

Nov. 14, about $23^h\ 30^m$, Torbreck. Four distinct noises heard, resembling distant cannon.

† Geol. Mag. (1883) p. 344.

Mr. A. Birnie, Rev. A. D. Mackenzie; Blackpool of Muistoun, Mr. T. Barclay; Boharm, Rev. J. D. Hunter, Rev. S. Ree; Boleskine, Mrs. MacIntyre; Bridge of Bruin, Mr. A. McIntosh; Brin, Mr. J. Smart; Bunchrew, Mr. W. Mackenzie; Bunchrubin, Miss J. Mackintosh; Burghead, Mr. W. Nicholson; Cawdor, Rev. C. MacGillivray; Chanonry Point lighthouse, Mr. D. MacKerrill; Clachnaharry, Mr. J. G. Davidson; Clunes station, Mr. D. Macaulay; Conon, Mr. J. McGregor; Corrimony, Mr. A. McDougall; Covesea lighthouse, Mr. T. Tulloch; Cromarty lighthouse, Mr. W. M. Mills; Cromdale, Rev. J. M. Cowan; Dalarossie, Mr. H. Bruce; Dalmunack, Mr. D. McBean; Dava, Mr. L. Murray; Daviot, Rev. J. Macdonald; Delrachnie, Mr. McKinnon; Dingwall, Mr. W. Morrison; Dores, Rev. T. Sinton; Drumnadrochit, Mr. D. D. Macdonald; Duffus, Mr. J. Young; Duthil, Mr. W. Rankine; Dyke, Rev. J. MacEwen; Edenkillie, Rev. A. Anderson; Elgin, Mr. G. Mitchell; Errogie, Mr. D. Smart; Evanton, Major R. Jackson; Feddan, Mr. M. Matheson; Fochabers, Rev. G. Birnie; Forres, Mr. T. Pullar; Fort George station, Mr. J. MacLeman; Fortrose, Mr. C. Laverie; Fowlis station, Mr. J. Gordon; Freeburn Hotel, Mr. K. Matheson; Garve, Rev. A. McDonald; Glass, Rev. D. M. Ross; Glassburn, Capt. Chisholm; Glencarron, Mr. D. Munro; Glenquoich, Mr. D. Grant; Glomach, Mr. H. Forbes; Golspie, Mr. H. A. Rye; Helmsdale, Police-Serjeant Anderson; Hopeman, Rev. J. Cassie; Inchbreen, Rev. E. Maclean; Invergarry, Mr. J. Grant; Invermoriston, Mr. W. Grant; Inverness, Messrs. F. A. Black and J. Moran; Keith, Rev. W. R. Price; Kildonan, Rev. D. Fraser; Kingussie, Mr. M. F. de Watteville; Kinloss, Rev. W. H. Edie; Kirkmichael, Rev. W. Grant; Lairg, Rev. D. Macrae; Lochhourn Head, Mr. A. Campbell; Lossiemouth, Rev. C. Tulloch; Moy, Mr. J. Watson; Nairn, Mr. C. Brodie; New Spynie, Rev. J. Garioch; Newtonmore, Mr. R. J. Kennedy; Nigg, Mr. T. W. Burt; Rafford, Rev. R. Smith; Strathpeffer, Mr. D. Cameron; Torbreck, Mr. G. Walker; Torness, Mr. G. Cameron; Urray, Rev. J. A. Macfarlane.

# GENERAL INDEX

TO

## THE QUARTERLY JOURNAL

AND

## PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

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# PROCEEDINGS

OF THE

# GEOLOGICAL SOCIETY OF LONDON.

## SESSION 1890–91.

November 12, 1890.

Dr. A. Geikie, F.R.S., President, in the Chair.

Sidney Howard Farrar, Esq., Assoc.M.Inst.C.E., Johannesburg, Port Elizabeth, and 69 Cornhill, E.C.; John H. Powell, Esq., P.O. Box 538, Johannesburg, Transvaal; and Horace Weldon, Esq., 159 Victoria Street, S.W., were elected Fellows of the Society.

Tempest Anderson, M.D., B.Sc., 17 Stonegate, York; Humphrey Purnell Blackmore, M.D., Salisbury, Wiltshire; William Young Campbell, Esq., 24 Gledstanes Road, West Kensington, W., and Johannesburg, South Africa; Joseph Frederick Crowder, Esq., Oxford Road, Macclesfield; William Thomas Curry, Esq., Assoc. M.Inst.C.E., Chelvey West Town, Somersetshire; Philip Latimer Davies, Esq., Science Demonstrator, Liverpool College, 40 Beaconsfield Street, Liverpool; G. Firth Franks, Esq., Harrison's College, Bridgetown, Barbados; Rev. Charles Frederick Bonney Hawkins, M.A., 87 Gloucester Place, W., and Grosvenor Club, W.; Rev. Ed. Jones, Rockville, Embsay, near Skipton; Nono Kitto, Esq., Foxdale, Isle of Man; Henry Albert Mangles, Esq., late Bengal Civil Service, Littleworth Cross, Tongham, Surrey; Edward P. Mathers, Esq., Glenalmond, Westwood Park, Forest Hill, S.E.; O. C. J. G. L. Overbeck, Esq., Glenville, Waterfoot, Manchester; Frank Owen, Esq., Sheen Lodge, Richmond Park, East Sheen, S.W.; James Villiers Parkes, Esq., Warden of Gold Fields and Acting Inspector of Mines for South Australia, Adelaide, South Australia; Peter John Roberts, Esq., 4 Shepherd Street, Bacup, Lancashire; Henry Sugg, Esq., Rostowe, Trent Road, Brixton Hill, S.W.; and Henry H. Sutherland, Esq., William Street, Bathurst, New South Wales, were proposed as Fellows of the Society.

The List of Donations to the Library was read.

The Secretary announced that an oil-painting of some Members of the Geological Section of the British Association Meeting, held at Newcastle-on-Tyne in 1838, painted by the late T. H. Gregg, Esq., had been presented to the Society by his daughter.

The President referred to the sad loss which the Society had sustained since the last Meeting, through the death of the late Foreign Secretary, Sir Warington W. Smyth, F.R.S.

The President reported that Mr. L. Belinfante had been temporarily appointed by the Council to the Office of Assistant-Secretary.

The following communications were read:—

1. "On the Porphyritic Rocks of the Island of Jersey." By Prof. A. De Lapparent, Foreign Correspondent of the Society. (Communicated by the President.)

2. "On a new Species of *Trionyx* from the Miocene of Malta, and a Chelonian Scapula from the London Clay." By R. Lydekker, Esq., B.A., F.G.S.

3. "Notes on Specimens collected by W. Gowland, Esq., F.C.S., in the Korea." By Thomas H. Holland, Esq., of the Geological Survey of India, late Berkeley Fellow of the Owens College. (Communicated by Prof. J. W. Judd, F.R.S., F.G.S.)

4. "Further Notes on the Stratigraphy of the Bagshot Beds of the London Basin (north side)." By the Rev. A. Irving, D.Sc., F.G.S.

[Abstract.]

The Author, having given reasons why the presence or absence of pipe-clay, false-bedding, or mica is not a criterion for the Lower-Bagshot Sands, independently of stratigraphical considerations, proceeded to bring forward new evidence from well-sections, clay-pits recently opened, and excavations, bearing upon the reading of the country between Wellington-College and Wokingham Stations, as put forward by him in 1887 (Q. J. G. S. vol. xliii. and figure 1 of the paper).

In particular, the Author stated that in Messrs. Monckton and Herries's section of the Middle-Bagshot Beds, along the railway (Q. J. G. S. vol. xlii. p. 407), the dip to the south is excessive and misleading; and he brings forward new evidence to show that the assumption that the sands at Wokingham represent the base of the series cannot hold good.

He has now actual data for the gradients of the clay-beds, and the thinning-out of both the Lower (fluviatile) Sands and of the Middle green-earth series; the latter, when taken into account, bringing the clays in the Wokingham outlier into the same horizon with the basal clays and brick-earths of the Middle Group to the south. The clays at California brick-yards are also shown to be in

alignment with these; and a sketch-section from Ambarrow to Barkham Hill shows the relative gradients of certain horizons to be such as to justify the relegation of the pebble-bed there to the base of the Upper Sands, owing to northerly dip on the north flank of Finchampstead Ridges; while a microscopical examination of the sands lends support to this conclusion.

The mapping of the Bagshot Beds as a pentad series (as worked out in former papers) was shown in colours on the two sheets of the six-inch Ordnance-Survey Map, which include the Wokingham and Wellington-College districts.

A section was drawn from Wellington-College Well through the sand-pit at the brick-yards by Ninemile Ride (8 ft. of the Middle Clays exposed), Easthampstead-Church Hill (with more recent data), and Bill Hill, to the South-Western Railway at Bracknell, bringing apparently the higher beds of those two hills into the horizon of the Upper Sands—recent excavations for building on the line of section at rather more than a mile north of Wellington College having demonstrated its accuracy for the critical portion of the ground.

In conclusion, the Author pointed out that the new well-sections confirm the order of superposition at Wellington College as a vertical datum-line; he criticized the views of previous writers and maintained that, with the aid of Lieut. Lyons's recently published contour-map, we can now discriminate between the effects of contemporaneous and post-Eocene earth-movements in the area; and that the physical history of the Bagshot Beds, which he has propounded, is further substantiated by the new stratigraphical evidence.

## Discussion.

Mr. Monckton believed the diagrams upon which the Author rested his case were very incorrect,—thus the clays below the beds of green sand in the Middle Bagshot do not extend to the north as drawn, but crop out near the far signal-post north of Wellington-College Station, and the well at the new cottages further north passes through sands, and not through clays into sand, as shown in the diagram; moreover, the cuttings at the Ninemile Ride are in yellow Lower-Bagshot sand, not in gravel.

As to the hills from Bearwood to Ascot, the Author's contention that they are Upper and Middle Bagshot fails, for there are excellent and characteristic Lower-Bagshot sections all along the line, *ex. gr.*:—Dowles-Farm sand-pit near Bearwood, 260 feet o.d.; Tangley railway-cutting, Wokingham; Coppid-Beech-Lane road-cutting; sand-pits at the top of the hill above Amen Corner, 275 feet o.d.; and at the top of Easthampstead-Church Hill, 280 feet o.d.; also sections at Bill Hill, Bracknell, and at the reservoir near Ascot Priory on Goathurst Hill, 305 feet o.d. Signs of green sand were also to be found at the tops of Bill Hill, Bracknell, and Burleigh, Ascot, showing that Middle Bagshot once existed above these hills, which could not therefore be Upper Bagshot.

Mr. J. H. Blake remarked that Dr. Irving, since he had given up the theory of overlap on the southern side, had persistently attempted to establish an overlap on the northern side of the London Basin, but he had seen no evidence of this. All the evidence between Ninemile Ride and Wokingham was in favour of Lower Bagshot. The bed which Dr. Irving had claimed as the basement of the Middle Bagshot in the Wokingham railway-cutting was considered by the speaker to be an alteration of the Lower-Bagshot Beds, due to the capping of gravel, and he saw no evidence of Middle Bagshot at Wokingham. At Easthampstead Church was a characteristic section of Lower-Bagshot Sands. He maintained the accuracy of the original description of the Bagshot Beds by Prof. Prestwich in 1847, subsequently confirmed by the Geological Survey.

Mr. Herries did not see much that was new in the paper. All the arguments concerning the well at Ambarrow rest on assumptions as to constancy of thickness of the same strata. Within ten minutes' walk of the sand-pit at Easthampstead Church were exactly similar sands, which the Author had previously admitted to be Lower Bagshot.

Mr. Whitaker agreed with the Author to a certain extent concerning mica, pipe-clay, and false-bedding, but the Author's opponents did not rely on isolated pieces of evidence of such nature, but rather on their combination. Not only had Prof. Prestwich advanced the old view, it had been accepted by the earlier Surveyors, and on later occasions other Surveyors had borne it out. With regard to the clays underlying the pebble-beds at Bearwood, Dr. Irving had originally described the pebble-beds as Upper Bagshot resting on London Clay, but there was 30 feet of Lower-Bagshot Sand below. At Bill Hill, Dr. Irving claimed the sand as Upper Bagshot; nevertheless, there was green sand of the Middle Bagshot higher up, either in place or but slightly moved. Dr. Irving's view landed us in great difficulties if we compared the northern and southern sides of the London Basin, here only 7 or 8 miles apart, for it supposed a different structure on those sides—a complicated arrangement instead of a simple one. Dr. Irving ought to show where these two different structures passed into one another on the east and on the west. The occurrence of pebbles merely proved that beds were somewhere between Woolwich and Headon horizons. He held that the burden of the proof rested with the Author, and he was afraid it was a burden greater than he could bear.

The Author, in reply, maintained that you could, as a whole, trace the green series, with its associated clays, through miles of country. The clays, of which labelled specimens were on the table, and which one speaker had stated to be non-existent, actually occurred in open pits where it was stated that the Lower Sands crop out. He had found reconstructed Middle-Bagshot clays over the Lower Sands near Dowles Farm, and the section was dealt with in the paper. He had based his arguments on relative levels to some extent as giving data for measurements; but he had also paid attention to similarities of lithological character. He had written

the paper because he had more facts recently brought to light. He had not assumed the northerly attenuation of the green-earth and quartz-sand series, but established it by scaling measurements based on actual data. The counter-testimony he had heard failed to carry conviction; the one fragment of counter-evidence demanded further investigation.

The following specimens were exhibited:—

Specimens exhibited by R. Lydekker, Esq., F.G.S., in illustration of his paper.

Rock-specimens and microscopic rock-sections, exhibited by Prof. J. W. Judd, F.R.S., F.G.S., on behalf of T. H. Holland, Esq., in illustration of his paper.

Specimens and photographs, exhibited by the Rev. A. Irving, D.Sc., F.G.S., in illustration of his paper.

Specimens of the green sand of the Middle Bagshots from Bear Hill, Bracknell, exhibited by W. Whitaker, Esq., F.R.S., F.G.S.

Model of the largest gold nugget yet found in Western Australia, known as the "Little Hero," weighing 330 oz. 8 dwts., found at Shaw's Fall, 200 miles from Roebourne and 80 from Nullagine, at a depth of 8 inches, exhibited by Harry Page Woodward, Esq., F.G.S.

A Special General Meeting was announced to be held on Wednesday, November 26th, 1890, at 7.45 P.M., before the Ordinary General Meeting, for the purpose of electing a new Member of Council and a Foreign Secretary; also for the purpose of sanctioning a gift of the sum of £50 to the Widow of the late Assistant-Secretary.

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November 26, 1890.

Dr. A. Geikie, F.R.S., President, in the Chair.

Frederick William Boam, Esq., F.C.S., Treragion, Harrowbarrow, and Coombe Mines and Works, Callington, Cornwall; and George Henry Cory Wright, Esq., 20 Camden Hill Road, Norwood, were elected Fellows of the Society.

Elliott Moore Cairnes, Esq., Mining Surveyor, Department of Mines, Melbourne, Victoria; John H. Cooke, Esq., Highland House, St. Julian's, Malta; Joseph James East, Esq., Assistant-Director, School of Mines and Industries, North Terrace, Adelaide, South Australia; Dawson Kitchingman, Esq., Assoc.Inst.C.E., The Laurels, Yatton, Somersetshire; Arthur Montefiore, Esq., 1 Marlbro' Road, Bedford Park, W.; Herbert Warington Smyth, Esq., B.A.,

5 Inverness Terrace, W., and The Cliff, Marazion; Henry Arthur Spalding, Esq., Geraldton, Western Australia; Umfreville Percy Swinburne, Esq., Capheaton Hall, Newcastle-on-Tyne; and William Roberts Thomas, Esq., Uranium Mines, Grampound Road, Cornwall, were proposed as Fellows of the Society.

The List of Donations to the Library was read.

The following names of Fellows of the Society were read out for the first time, in conformity with the Bye-laws, Section VI. Article 5, in consequence of the non-payment of their arrears of contributions:—R. N. Boyd, Esq.; F. B. Henderson, Esq.

The appointment of Mr. L. Belinfante as Assistant-Secretary was confirmed.

The following communications were read:—

1. "Account of an Experimental Investigation of the Law that Limits the Action of Flowing Streams." By R. D. Oldham, Esq., A.R.S.M., F.G.S., Deputy Superintendent of the Geological Survey of India.

[Abstract.]

The Author brings forward evidence, derived from experiments, in support of the views expressed in a paper submitted to the Society in 1888. His apparatus consisted of a sloping trough, through which various amounts of water containing definite percentages of sand could be sent. The lower end of the trough issued on to a semicircular platform.

In experiments with the trough at a slope of 1 in 20, and with the same supply of sand in each case, the resulting slopes after sand had accumulated in the trough were as follows:—With one part of sand to 42 of water, a slope of 1 in 40; with 1 of sand to 28 of water, 1 in 20; and with 1 of sand to 14 of water, 1 in 13·3. These slopes were obtained when a stable condition had been arrived at, in which the water was just able to transport its burden. By changing the supply of water from one to another of these values the corresponding slopes were obtained.

On the fan formed on the horizontal platform variations in the water-supply did not produce nearly so marked an effect as in the confined channel, and the slope varied considerably in different directions.

After a time a channel was cut back from the margin of the fan, and its sand was swept forward and deposited as a secondary fan in front of the first; and as the channel grew, it cut back into the reach above, and this in turn cut back towards the head of the fans, and sometimes into the trough. In some cases other secondary fans were formed on the margin of the main fan, but the apparatus was not large enough for further formations. The general slope of the

fans, both primary and secondary, was ·06, 1 in 16, and that of the reach only ·04, 1 in 25, while at the head of the reach, where it was cutting back into the face above, there was a gradient of ·08, 1 in 12.

The general tendency of the experiments supports not only the specific conclusions of the former paper as to the normal form and behaviour of a river which has attained a state of equilibrium, but to a greater degree the fundamental assumption that a river will adapt its channel to such a slope and form as will enable it to just transport a solid burden cast upon it.

### Discussion.

Dr. Blanford found it difficult to follow the paper without seeing the experiments. He himself had somewhat misunderstood the Author's previous paper. He called attention to the fact that the state of equilibrium in streams never lasts long. The paper was rather, therefore, of interest to engineers than to geologists; but the Author had done good service to science by making a series of experiments to test his geological conclusions.

Mr. Binnie had, as an engineer, conducted experiments of a somewhat similar nature, and found the problem practically insoluble, owing to the varying conditions; and he considered caution should be exercised in arguing from so limited a series of experiments.

Mr. Topley called attention to the experiments made by a Committee of the British Association with reference to the flow of water into estuaries.

The President was not satisfied, from the brief abstract he had heard, that the few experiments described furnished sufficient data for the conclusions.

## 2. "On the Rocks of North Devon." By Henry Hicks, M.D., F.R.S., Sec.G.S.*

[Abstract.]

During a recent visit to North Devon the Author obtained evidence which has led him to believe that far too little importance has hitherto been assigned to the results of movements in the Earth's crust as affecting the succession of the rocks in that area. The supposed continuous upward succession from the rocks on the shore of the Bristol Channel to those in the neighbourhood of Barnstaple, including, according to some authors, no less than ten groups, and classed into three divisions under the names Lower, Middle, and Upper Devonian, is, the Author believes, an erroneous interpretation. The beds, he says, have been greatly plicated and faulted, and consequently several times repeated, and instead of

* Withdrawn by the Author with the permission of the Council.

being one continuous series, they occur folded in more or less broken troughs. In the Morte Slates, previously considered unfossiliferous, the Author found a *Lingula*, and he believes that these slates are the oldest rocks in the area, and formed the floor upon which the Devonian Rocks were deposited unconformably. As the result of movements in the Earth's crust, the Morte Slates have been brought to the surface and thrust over much newer rocks, producing a deceptive appearance of overlying the latter conformably. The Morte Slates mark the dividing line between the two main troughs. On the north side in ascending order are the Hangman (or Lynton), Combe-Martin Bay, and Ilfracombe Beds, and on the south side the Pickwell-Down, Baggy-Point, and Pilton Beds. Those on the south side of the Morte Slates are, the Author believes, a repetition of the beds on the north side. The palæontological evidence is not antagonistic to this view, for an analysis of the Brachiopoda, the only group of fossils in the beds on the south side which hitherto have been systematically examined, shows that of the twenty species mentioned by Mr. Davidson and others as occurring in the Pickwell-Down, Baggy-Point, and Pilton Beds (the so-called Upper-Devonian Rocks), no less than thirteen have already been found in the Middle- or Lower-Devonian Rocks on the north side of the Morte Slates. Four others are recognized Middle-Devonian species in other areas; and the three remaining are either doubtful species or have a great vertical range. These facts show that the so-called Upper-Devonian Rocks in this area do not contain a distinguishing fauna of any importance; and the stratigraphical evidence is opposed to the view that they are a series of rocks distinct from those on the north side of the Morte Slates, which have been classed as Middle and Lower Devonian.

## Discussion.

Mr. T. Roberts began with the stratigraphical evidence. The *Lingula* found in the Morte Slates gave no evidence of age; and he believed the high dip in the Morte Slates was of no value as differentiating those slates from the other beds. Certain zones of the Hangman Beds are crowded with fossils, and these are not found in the Pickwell-Down region. He objected to the Brachiopods only being chosen for purposes of correlation, and thought the doubtful specimens told either way. The Baggy and Pilton Beds, according to the Author, are similar to those associated with *Stringocephalus Burtini*. Twelve out of nineteen species of Brachiopods in the Baggy and Pilton Beds pass into the Carboniferous, whilst only five pass down into the Ilfracombe series. *Phacops latifrons* is stated to be abundant in Middle Devonian of South Devon; but many of these are probably *Phacops batracheus*. *Ph. latifrons* had been found on the Continent in beds of Lower-, Middle-, and Upper-Devonian age. He had analyzed the Baggy and Pilton fossils, and out of the 120 species he had been able to give generic names only

to 30 species, probably mostly new. Of the 90 named species, 19 passed from Lower Devonian into Carboniferous, 12 from Lower Devonian to Pilton; these should not be taken into consideration. Of the remaining 59, 23 pass up into the Carboniferous, whilst only 12 pass down into the Ilfracombe Beds. The species characteristic of Baggy and Pilton Beds are 24, of which 10 are recorded from Upper-Devonian Beds of other areas. In correlating these beds with those of Continental regions, similar results are obtained. The Baggy Beds are certainly on the horizon of the Upper-Devonian Beds of Belgium. He believed, therefore, that the palæontological evidence was clearly in favour of the old succession.

Mr. Marr saw difficulties in supposing that the differences between the junction of the Baggy Beds and the Morte Slates, and that of the beds at Combe Martin with the Hangman Grits, could be accounted for by the faulting-out of some of the beds near Combe Martin. As the result of a hasty inspection, he was rather inclined to favour the notion of an upward passage from the Ilfracombe Beds into the Morte Slates. If he had understood the paper aright, the Author would place the Pilton Beds, with their undoubted Carboniferous affinities, under the Great Devon Limestone; this appeared to him to be almost a return to the doctrine of Colonies, with which he could not agree, and it was entirely contrary to the conclusions of both Prof. Jukes and Mr. Etheridge.

Prof. Seeley had made several traverses of North Devon in search of faults when Prof. Jukes's views engrossed attention, but had seen no trace of the faults which were necessary to Prof. Jukes's theory. He hoped, when Dr. Hicks's views were published, he would insert localities where the faults can be seen and traced, in order that those who differed from his views might know exactly where to look. He confirmed Mr. Roberts's conclusions concerning the Carboniferous facies of the Upper-Devonian fauna of the Baggy Beds.

Mr. H. B. Woodward had elicited a letter containing Mr. Ussher's views. The latter considered that Dr. Hicks had not weighed the evidence contained in the literature of the North-Devon Rocks, where it was absolutely demonstrated that the three grit series were quite distinct. The Morte Slates were in their true position, as shown in West Somerset and near Dulverton. The Cucullæa-zone did not come in the Lower series of slates. The development of grits in the North-Devon area was a natural consequence of the geographical conditions in that area. He believed Dr. Hicks's thrust-planes were imaginary. The speaker remarked, on his own behalf, that it was not demonstrated that the three sandstone bands were all different, and if the Foreland sandstones were the same as the Hangmans, we should only have two sandstones to deal with. Mr. Ussher had shown that the Cockington and Warberry grits were the same. He believed the Torquay coral-limestones must come in below the Pilton Beds; but the higher beds of the South-Devon limestone, of Chudleigh and Petherwin, yielded some Carboniferous species, and these beds were overlain by strata yielding *Posidonomya* and *Gonia-*

*tites*, such as characterize the upper part of the Carboniferous Limestone elsewhere.

Rev. H. H. Winwood believed the Author's stratigraphical and palæontological evidence was weak. The Author mentioned that the Hangman Grits were comparatively unfossiliferous, but there are at least 10 species, including *Natica*, none of which have been found by Dr. Hicks in the Pickwell-Down Beds, a difficulty to be explained if he correlates them with the Hangman Grits.

Rev. G. F. Whidborne remarked that *Phacops latifrons* had a wide range in South Devon. The number of Carboniferous forms went to prove that the beds in the north were very much higher than the Great Devon Limestone.

Mr. Hudleston wished to know how the beds were got into the position represented in the diagram.

Prof. Blake asked whether the Pilton Beds did not pass up into the Carboniferous.

The President remarked that, in altering the recognized order of succession of these rocks, the Author would have to reckon also with Continental stratigraphers and palæontologists. Dr. Hicks had not made as clear as might be the evidence for such thrust-planes and faults as his views of the structure of the ground required. The plications and dislocations in South Devon and Cornwall, although abundant and often very complicated, appeared to the speaker to be on a comparatively small scale; and although he did not wish to insist that this must be the case in North Devon, he felt that it might be so.

The Author, in reply, stated that he had gone carefully into Continental questions, and he maintained they were strongly in his favour. He declared that there was ample evidence to show that there was any amount of thrusting in North Devon. The Hangman Grits in Combe-Martin Bay have three sharp folds against the fault, indicating that beds are missing, and he maintained that even in the Hangman Beds the palæontological evidence was in favour of his views. Mr. Valpy had found *Cucullæa* in these beds, and two species are given in Mr. Roberts's list of the Hangman fauna. Along the Tors he found that every one was a broken fold, though there was no great thrusting there, and these beds abutted against the Morte Slates. He had no means of calculating the amount of the equivalents of the Baggy-Pilton Beds lost at the Combe-Martin fault. He had carefully considered all the evidence placed on record, therefore Mr. Ussher's remarks seemed unwarranted. The thickness claimed by the supporters of a continuous upward succession was about 15,000 feet, indicating, of course, a gradual depression to that extent. This, he maintained, was impossible in the face of the lithological evidence, and of facts obtained from neighbouring areas; moreover, it would necessitate that such a characteristic zonal fossil as *Stringocephalus Burtini* should be placed at the base of the Ilfracombe Beds (shore of Combe-Martin Bay), and therefore separated from its closely associated fossils (Baggy and Pilton fauna) by about 10,000 feet of strata. He

maintained that there was but one series, and that the thickness was less than a third of that usually given. He correlated the Pilton Beds, as shown in the map and section, with the higher carbonaceous slates and calcareous beds in the Ilfracombe trough. It was quite possible that the Pilton Calcareous Shales represented limestone-beds elsewhere. *Phacops latifrons*, according to Mr. Whidborne's view, ought to go into the Carboniferous. He maintained that Mr. Roberts's own list, as furnished to him, supported his (the Author's) view. Doubtful species, determined from imperfect material obtained from one area only, should not be used as evidence, especially against that derived from well-recognized fossils. The Morte-Slates *Lingula* was certainly not a Devonian species, but evidently a much older form.

The following specimens were exhibited:—

Specimens and photographs exhibited by Dr. H. Hicks, F.R.S., Sec.G.S., in illustration of his paper.

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A Special General Meeting was held at 7.45 o'clock P.M., before the Ordinary General Meeting, at which J. W. Hulke, Esq., F.R.S., was elected Foreign Secretary, and J. J. H. Teall, Esq., F.R.S., was elected a Member of Council; also a gift of a sum of £50 to the Widow of the late Assistant-Secretary was sanctioned.

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## December 10, 1890.

Dr. A. Geikie, F.R.S., President, in the Chair.

Tempest Anderson, M.D., B.Sc., 17 Stonegate, York; Humphrey Purnell Blackmore, M.D., Salisbury, Wiltshire; William Young Campbell, Esq., 24 Gledstanes Road, West Kensington, W., and Johannesburg, South Africa; Joseph Frederick Crowder, Esq., Oxford Road, Macclesfield; William Thomas Curry, Esq., Assoc. M.Inst.C.E., Chelvey West Town, Somersetshire; Philip Latimer Davies, Esq., Science Demonstrator, Liverpool College, 40 Beaconsfield Street, Liverpool; G. Firth Franks, Esq., B.A., Harrison's College, Bridgetown, Barbados; Rev. Charles Frederick Bonney Hawkins, M.A., 87 Gloucester Place, W., and Grosvenor Club, W.; Rev. Ed. Jones, Rockville, Embsay, near Skipton; Nono Kitto, Esq., Foxdale, Isle of Man; Henry Albert Mangles, Esq., late Bengal Civil Service, Littleworth Cross, Tongham, Surrey; Edward P. Mathers, Esq., Glenalmond, Westwood Park, Forest Hill, S.E.; O. C. J. G. L. Overbeck, Esq., Glenville, Waterfoot, Manchester; Frank Owen, Esq., Sheen Lodge, Richmond Park, East Sheen, S.W.; James Villiers Parkes, Esq., Warden of Gold-Fields and Acting Inspector

of Mines for South Australia, Adelaide, South Australia; Peter John Roberts, Esq., 4 Shepherd Street, Bacup, Lancashire; Henry Sugg, Esq., Rostowe, Trent Road, Brixton Hill, S.W.; and Henry H. Sutherland, Esq., William Street, Bathurst, New South Wales, were elected Fellows of the Society.

William Henry Fitton, Esq., Highpits House, Beeston, Leeds; Andrés Franchy, Esq., B.A. (Seville), Assoc.R.S.M., Las Palmas, Grand Canary, and care of Messrs. Kolp and Co., Manchester; and Ernest William Wetherell, Esq., 48 Conduit Street, W., were proposed as Fellows; Dr. Charles Barrois, Lille, as a Foreign Member; and Prof. W. Dames, Berlin, and Dr. Emmanuel Kayser, Marburg, as Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The following names of Fellows of the Society were read out for the second time, in conformity with the Bye-laws, Section VI. Article 5, in consequence of the non-payment of their arrears of contributions:—R. N. Boyd, Esq.; F. B. Henderson, Esq.

The following communications were read:—

1. "On some Water-worn and Pebble-worn Stones taken from the Apron of the Severn Commissioners' Weir erected across the River at Holt Fleet, about 8 miles above Worcester." By Henry John Marten, Esq., M.Inst.C.E., F.G.S., Engineer to the Severn Commissioners.

2. "On the Physical Geology of Tennessee and adjoining Districts in the United States of America." By Prof. Edward Hull, M.A., LL.D., F.R.S., F.G.S., late Director of the Geological Survey of Ireland.

3. "On certain Ornithosaurian and Dinosaurian Remains." By R. Lydekker, Esq., B.A., F.G.S.

The following specimens were exhibited:—

Specimen of portion of stone and photographs of six stones taken from the apron of Holt Weir, exhibited by H. J. Marten, Esq., F.G.S., in illustration of his paper.

Casts of specimens, exhibited by R. Lydekker, Esq., F.G.S., in illustration of his paper.

December 17, 1890.

W. H. HUDLESTON, Esq., F.R.S., Vice-President, in the Chair.

Elliott Moore Cairnes, Esq., Mining Surveyor, Department of Mines, Melbourne, Victoria; John H. Cooke, Esq., Highland House, St. Julian's, Malta; Joseph James East, Esq., Assistant-Director, School of Mines and Industries, North Terrace, Adelaide, South Australia; Dawson Kitchingman, Esq., Assoc.Inst.C.E., The Laurels, Yatton, Somersetshire; Arthur Montefiore, Esq., 1 Marlbro' Road, Bedford Park, W.; Herbert Warington Smyth, Esq., B.A., 5 Inverness Terrace, W., and The Cliff, Marazion; Henry Arthur Spalding, Esq., Geraldton, Western Australia; Umfreville Percy Swinburne, Esq., Capheaton Hall, Newcastle-on-Tyne; and William Roberts Thomas, Esq., Uranium Mines, Grampound Road, Cornwall, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On Nepheline Rocks in Brazil.—II. The Tingua Mass." By O. A. Derby, Esq., F.G.S.

2. "The Variolitic Diabase of the Fichtelgebirge." By J. Walter Gregory, Esq., F.G.S., of the British Museum (Natural History).

The following specimens were exhibited:—

Rock-specimens and photographs exhibited by O. A. Derby, Esq., F.G.S., in illustration of his paper.

Rock-specimens and photographs exhibited by J. W. Gregory, Esq., F.G.S., in illustration of his paper.

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January 7, 1891.

Dr. A. GEIKIE, F.R.S., President, in the Chair.

William Henry Fitton, Esq., Highpits House, Beeston, Leeds; Andrés Franchy, Esq., B.A. (Seville), Assoc.R.S.M., Las Palmas, Grand Canary, and care of Messrs. Kolp and Co., Manchester; and Ernest William Wetherell, Esq., 48 Conduit Street, W., were elected Fellows; Dr. Charles Barrois, Lille, was elected a Foreign Member;

and Prof. W. Dames, Berlin, and Dr. Emmanuel Kayser, Marburg, were elected Foreign Correspondents of the Society.

Zacharie de V. Fonnereau, Esq., Glen Rosa, Carpinteria, Santa Barbara County, California, U.S.A.; William Edward Garforth, Esq., Halesfield, Normanton, Yorkshire; Thomas H. Holland, Esq., A.R.C.S., Assistant-Superintendent of the Geological Survey of India, Geological Survey Office, Calcutta; Edward Keller, Esq., B.Sc. Lond., Southfield House, Combe Down, Bath; Henry Lakin Lawrence, Esq., Cowper's Mansions, Leete Street, King's Road, Chelsea, S.W.; and Richard Startin Owen, Esq., B.A., Sheen Lodge, Richmond Park, East Sheen, S.W., were proposed as Fellows of the Society.

The following Fellows, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year:—F. G. H. Price, Esq.; Prof. J. F. Blake.

The List of Donations to the Library was read.

The following communications were read:—

1. "On the North-west Region of Charnwood Forest, with other Notes." By the Rev. E. Hill, M.A., F.G.S., and Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S.

2. "Note on a Contact-Structure in the Syenite of Bradgate Park." By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S.

3. "On the Unconformities between the Rock-Systems underlying the Cambrian Quartzite in Shropshire." By Charles Callaway, D.Sc., F.G.S.

The following specimens were exhibited:—

Rock-specimens and microscopic sections, exhibited by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S., in illustration of his paper.

Rock-specimens and microscopic sections, exhibited by Dr. C. Callaway, M.A., F.G.S., in illustration of his paper.

January 21, 1891.

Dr. A. Geikie, F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. "On the Age, Formation, and Successive Drift Stages of the Valley of the Darent; with Remarks on the Palæolithic Implements of the District, and on the Origin of the Chalk Escarpment." By Professor Joseph Prestwich, D.C.L., F.R.S., F.G.S., &c.

2. "On *Agrosaurus Macgillivrayi* (Seeley), a Saurischian Reptile from the N.E. coast of Australia." By Professor H. G. Seeley, F.R.S., F.G.S.

3. "On *Saurodesmus Robertsoni* (Seeley), a Crocodilian Reptile from the Rhætic of Linksfield, in Elgin." By Professor H. G. Seeley, F.R.S., F.G.S.

The following specimens were exhibited:—

Flint implements, exhibited by Messrs. de B. Crawshay, B. Harrison, and A. M. Bell, in illustration of Prof. Prestwich's paper.

Specimens of *Thenarocrinus callipygus* and *Th. gracilis*, from the Upper-Wenlock Limestone of Dudley; specimens of *Cyathocrinus* from the Keokuk Group, Indiana Creek, Montgomery Co., Indiana, showing the tegmen and ambulacra, and especially the modified anal interradial, which had been regarded by some palæontologists as a madreporite; and a rare Crinoid cup from the Niagara Limestone of St. Paul, Decatur Co., Indiana, exhibited by F. A. Bather, Esq., M.A., F.G.S.

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February 4, 1891.

Dr. A. Geikie, F.R.S., President, in the Chair.

Zacharie de V. Fonnereau, Esq., Glen Rosa, Carpinteria, Santa Barbara County, California, U.S.A.; William Edward Garforth, Esq., Halesfield, Normanton, Yorkshire; Thomas H. Holland, Esq., A.R.C.S., Assistant-Superintendent of the Geological Survey of India, Geological Survey Office, Calcutta; Edward Keller, Esq., B.Sc. (Lond.), Southfield House, Combe Down, Bath; Henry Lakin Lawrence, Esq., Cowper's Mansions, Leete Street, King's Road, Chelsea, S.W.; and Richard Startin Owen, Esq., B.A., Sheen Lodge, Richmond Park East Sheen, S.W., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. "The Geology of Barbados and the West Indies.—Part I. The Coral Rocks." By A. J. Jukes-Browne, Esq., F.G.S., and Professor J. B. Harrison, M.A., F.G.S.

2. "The Shap Granite, and the Associated Igneous and Metamorphic Rocks." By Alfred Harker, Esq., M.A., F.G.S., and J. E. Marr, Esq., M.A., Sec. G.S.

The following specimens were exhibited :—

Microscopic sections and specimens of rocks and fossils from Barbados, together with photographs, exhibited by Messrs. E. Easton, W. Hill, and A. J. Jukes-Browne, in illustration of the latter's paper.

Rock-specimens and microscopic sections, exhibited by Messrs. A. Harker and J. E. Marr, in illustration of their paper.

## *ANNUAL GENERAL MEETING,*

February 20, 1891.

Dr. A. Geikie, F.R.S., President, in the Chair.

### Report of the Council for 1890.

In presenting their Report for the year 1890, the Council have much pleasure in congratulating the Fellows on the continued prosperity of the Society, as evinced by its increasing number and by the very satisfactory condition of its finances.

The number of Fellows elected during the year was 76, of whom 56 paid their fees before the end of the year, making with 16 previously elected Fellows who paid their fees in 1890, and 1 Fellow re-admitted without payment of entrance-fee, a total accession during the year of 73 Fellows. During the same period there was, however, loss by death of 23 Fellows, and by resignation of 11 Fellows; moreover, 12 Fellows were removed from the list for non-payment of their annual contributions, there being thus a total loss of 46 Fellows. The actual increase in the number of Fellows is therefore 27. Of the 23 Fellows deceased, 7 were Compounders, 10 Contributing Fellows, and 6 non-Contributing Fellows. In the course of the year 10 compounded for their Annual Contributions, so that the actual increase in the number of Contributing Fellows is 30, making a total of 886.

The total number of Fellows, Foreign Members, and Foreign Correspondents was 1379 at the end of 1889, and 1405 at the close of the year 1890.

During the last-named year, 3 Foreign Members died and 2 were elected, 1 vacancy remaining in the list of Foreign Members at the end of 1890. At the end of 1889 there were 2 vacancies in the list of Foreign Correspondents, and in the course of the following year news was received of the death of 2 Foreign Correspondents; 4 vacancies were filled during the year by election, but there were still 2 vacancies in the list at the end of 1890.

The statement of the Society's Income and Expenditure during 1890 may be summarized briefly as follows:—

During that year the total Receipts on account of Income (not including the proceeds of sale of Stock for re-investment) amounted to £3034 8*s.* 1*d.*, being £354 3*s.* 5*d.* more than the estimated Income for 1890. On the other hand, the current Expenditure of that year (leaving out of account sums expended in purchase of Stock and re-investment) amounted to £2429 16*s.* 2*d.*, being £213 13*s.* 10*d.* less than the estimated Expenditure for 1890. The actual excess of Receipts over Expenditure during that year therefore amounted to £604 11*s.* 11*d.*, and the Balance in favour of the Society to £433 17*s.* 6*d.*

A re-investment of Stock was made in the following manner:—£5230 17*s.* 6*d.* of Consolidated $2\frac{3}{4}$ per cent. Government Stock was sold, realizing £5139 6*s.* 9*d.* There was then purchased £2000 of London and North-Western Railway 4 per cent. Consolidated Preference Stock costing £2575 13*s.*, and £2000 of London and South-Western Railway 4 per cent. Consolidated Preference Stock costing £2563 2*s.* 3*d.* Further, the following small investments were made: the sum of £97 12*s.* 6*d.* was expended in the purchase of £100 of Consolidated $2\frac{3}{4}$ per cent. Government Stock, and the sum of £322 17*s.* 6*d.* in the purchase of £250 of London and North-Western Railway 4 per cent. Consolidated Preference Stock.

The Council desire to record the completion of Volume XLVI., and the commencement of Volume XLVII. of the Society's Journal. It is fitting to mention in this place that the task of editing the last two numbers of Vol. XLVI. was undertaken by Professor T. Rupert Jones, F.R.S.

The Council wish moreover to announce that the late Mr. Ormerod's Third Supplement to his Index to the Publications of the Society has now been published.

The Society during the past year has suffered two great losses by the death of its distinguished Foreign Secretary and its faithful Assistant Secretary. Sir Warington Smyth was one of the oldest and most esteemed Fellows, and up to the very end of his long and active life continued to take a lively interest in the welfare and management of the Society.

Mr. Dallas, by his long and diligent discharge of his duties, rendered important service to the Society. As an expression of their recognition of this service and of their deep regret at his death, the Council recommended that a sum of £50 should be granted to Mrs. Dallas, and this recommendation was unanimously approved at a Special General Meeting of the Society.

During the six months which elapsed between the decease of Mr. Dallas and the entrance upon his duties of the present Assistant Secretary, an unusual amount of labour and responsibility necessarily devolved upon the Assistant Librarian and the Assistant Clerk, whose services the Council gladly recognize and to each of whom a gratuity of £25 has been given.

The Council have made the following awards of medals and memorial funds:—

The Wollaston Medal has been awarded to Professor J. W. Judd, F.R.S., in recognition of the important services rendered by him to geological science, especially in the department of Petrology.

The Murchison Medal has been awarded to Professor W. C. Brögger, of Christiania, in recognition of the value of his researches amongst the rocks of Scandinavia.

The Lyell Medal, with a sum of £25 from the proceeds of the Fund, has been awarded to Professor T. McK. Hughes, M.A., F.R.S., in token of appreciation of his investigations in various departments of Geology, and especially amongst the older rocks of Great Britain.

The Bigsby Medal has been awarded to Dr. G. M. Dawson, F.G.S., of Ottawa, in acknowledgment of his researches amongst the rocks of North America.

The balance of the proceeds of the Wollaston Donation Fund has been awarded to R. Lydekker, Esq., B.A., F.G.S., in token of appreciation of his work in Vertebrate Palæontology, and for the purpose of assisting him in the further prosecution of his researches.

The balance of the proceeds of the Murchison Geological Fund has been awarded to the Rev. R. Baron, F.L.S., as a testimony of the value of his work in Madagascar, and for the purpose of aiding him in further research.

The balance of the proceeds of the Lyell Geological Fund has been awarded to Dr. Forsyth-Major and G. W. Lamplugh, Esq., F.G.S., in token of appreciation of their work, and for the purpose of aiding them in the further prosecution of their researches.

## Report of the Library and Museum Committee for the year 1890.

The Committee have much pleasure in announcing that since the last Anniversary Meeting a number of valuable additions have been made to the Library, both by donation and by purchase.

As Donations the Library has received about 107 Volumes of separately published works and Survey Reports, and 209 Pamphlets, besides about 141 Volumes and 58 detached Parts of the publications of various Societies. Moreover, 18 Volumes of Newspapers have been received. This constitutes a total addition to the Society's Library, by donation, of about 277 Volumes and 209 Pamphlets.

The Library has further received by presentation 51 Maps and Plans.

The Books, Maps, &c. referred to above were presented by 133 personal Donors, the Editors or Publishers of 7 Periodicals, and 135 Societies, Surveys, and other Public Bodies, making in all 275 Donors.

By purchase, on the recommendation of the Standing Library Committee, the Library has received the addition of 22 Volumes of separately published works, 15 parts of works published as serials, and of 61 Volumes and 66 Parts of various periodicals.

Among the last named are included 36 Volumes of "Petermann's Mittheilungen" and 20 Volumes of the "Ergänzungshefte" to the same publication.

Of the "Carte géologique détaillée de la France," 3 sheets have been obtained by purchase; there was also purchased F. Noe's "Geologische Uebersichtskarte der Alpen."

The cost of Books, Periodicals, and Maps purchased during the year 1890 was £123 1*s.* 6*d.*, and that of Binding £69 15*s.* 1*d.*, amounting in all to £192 16*s.* 7*d.*

### *Museum.*

No additions have been made to the collections in the Museum during the past year.

The small sum of £3 0*s.* 7*d.* was expended on "glass and labour" in this department, and the glazing of the Inner Museum has now been brought to completion.

COMPARATIVE STATEMENT OF THE NUMBER OF THE SOCIETY AT THE CLOSE OF THE YEARS 1889 AND 1890.

| | Dec. 31, 1889. | Dec. 31, 1890. |
|---|---|---|
| Compounders | 310 | 313 |
| Contributing Fellows | 856 | 886 |
| Non-contributing Fellows | 135 | 129 |
| | 1301 | 1328 |
| Foreign Members | 40 | 39 |
| Foreign Correspondents | 38 | 38 |
| | 1379 | 1405 |

*Comparative Statement explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years* 1889 *and* 1890.

| | | | |
|---|---|---|---|
| Number of Compounders, Contributing and Non-contributing Fellows, 31 December, 1889 | | | 1301 |
| *Add* Fellows elected during former year and paid in 1890 | | | 16 |
| *Add* Fellows elected and paid in 1890 | | | 56 |
| *Add* Fellow re-elected who paid no Admission Fee | | | 1 |
| | | | 1374 |
| *Deduct* Compounders deceased | | 7 | |
| Contributing Fellows deceased | | 10 | |
| Non-contributing Fellows deceased | | 6 | |
| Contributing Fellows resigned | | 11 | |
| Contributing Fellows removed | | 12 | |
| | | — | 46 |
| | | | 1328 |
| Number of Foreign Members and Foreign Correspondents, 31 December, 1889 | | 78 | |
| *Deduct* Foreign Members deceased | 3 | | |
| Foreign Correspondents deceased | 2 | | |
| Foreign Correspondents elected Foreign Members | 2 | | |
| | — | 7 | |
| | | 71 | |
| *Add* Foreign Members elected | | 2 | |
| Foreign Correspondents elected | | 4 | |
| | | — | 77 |
| | | | 1405 |

## Deceased Fellows.

*Compounders* (7).

Adamson, S. A., Esq.
Dickinson, F. H., Esq.
Johnston, C., Esq.
Noble, J., Esq.
Paine, Dr. W. H.
Parker, Major F. G. S.
Smyth, Sir Warington W.

*Resident and other Contributing Fellows* (10).

Adamson, D., Esq.
Backhouse, J., Esq.
Barstow, C. D., Esq.
Fleming, T. J. G., Esq.
Gibson, T. F., Esq.
Howe, W. E., Esq.
Hurst, T. G., Esq.
Mylne, R. W., Esq.
Stevenson, G. W., Esq.
Taafe, A., Esq.

*Non-contributing Fellows* (6).

Beckles, S. H., Esq.
Cossham, H., Esq.
Dorrington, J., Esq.
Gunn, J., Esq.
Home, Dr. D. M.
Quiros, F., Esq.

*Foreign Members* (3).

Favre, Prof. A.
Hébert, Prof. E.
Quenstedt, Prof. F. A. von.

*Foreign Correspondents* (2).

Martins, Dr. C.
Neumayr, Prof. M.

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## Fellows Resigned (11).

Benton, W. E., Esq.
Craven, A. E., Esq.
Cruttwell, A. C., Esq.
Edgell, A. W., Esq.
Ellis, W. H., Esq.
Knobel, E. B., Esq.
Martin, J. S., Esq.
Radford, E., Esq.
Rideal, Dr. S.
Rowe, Rev. A. W.
Webb, F. J., Esq.

### Fellows Removed (12).

| | |
|---|---|
| Barry, J. W., Esq. | Jordon, E., Esq. |
| Gascoyne, R., Esq. | Leonard, H., Esq. |
| Granville, Dr. J. M. | Moore, Capt. E. St. F. |
| Guppy, Dr. H. B. | Ruddle, D., Esq. |
| Henderson, R., Esq. | Williams, Rev. W. |
| Johnson, H., Esq. | Young, Dr. J. |

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*The following Personages were elected from the List of Foreign Correspondents to fill the vacancies in the List of Foreign Members during the year* 1890.

Professor Heinrich Rosenbusch, of Heidelberg.
Herr Dionys Stur, of Vienna.

*The following Personages were elected Foreign Correspondents during the year* 1890.

Mons. Gustave F. Dollfus, of Paris.
Herr Felix Karrer, of Vienna.
Professor Adolph von Könen, of Göttingen.
Mons. Friedrich Schmidt, of St. Petersburg.

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After the Reports had been read, it was resolved :—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved :—

That the thanks of the Society be given to Prof. A. H. Green, the Rev. Edwin Hill, Major-Gen. C. A. McMahon, E. T. Newton, Esq., and the Rev. G. F. Whidborne, retiring from the Council.

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After the Balloting-glasses had been duly closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year :—

## OFFICERS.

*PRESIDENT.*

A. Geikie, LL.D., F.R.S.

*VICE-PRESIDENTS.*

W. T. Blanford, LL.D., F.R.S.
Prof. T. G. Bonney, D.Sc., LL.D., F.R.S.
L. Fletcher, Esq., M.A., F.R.S.
W. H. Hudleston, Esq., M.A., F.R.S.

*SECRETARIES.*

H. Hicks, M.D., F.R.S.
J. E. Marr, Esq., M.A.

*FOREIGN SECRETARY.*

J. W. Hulke, Esq., F.R.S.

*TREASURER.*

Prof. T. Wiltshire, M.A., F.L.S.

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## COUNCIL.

Prof. J. F. Blake, M.A.
W. T. Blanford, LL.D., F.R.S.
Prof. T. G. Bonney, D.Sc., LL.D., F.R.S.
James Carter, Esq.
James W. Davis, Esq., F.L.S.
John Evans, D.C.L., LL.D., F.R.S.
L. Fletcher, Esq., M.A., F.R.S.
C. Le Neve Foster, D.Sc., B.A.
A. Geikie, LL.D., F.R.S.
A. Harker, Esq., M.A.
J. C. Hawkshaw, Esq., M.A.
H. Hicks, M.D., F.R.S.
G. J. Hinde, Ph.D.
W. H. Hudleston, Esq., M.A., F.R.S.
Prof. T. McKenny Hughes, M.A., F.R.S.
J. W. Hulke, Esq., F.R.S.
J. E. Marr, Esq., M.A.
H. W. Monckton, Esq.
F. W. Rudler, Esq.
J. J. H. Teall, Esq., M.A., F.R.S.
W. Topley, Esq., F.R.S.
Prof. T. Wiltshire, M.A., F.L.S.
H. Woodward, LL.D., F.R.S.

# LIST OF
# THE FOREIGN MEMBERS
## OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1890.

Date of Election.

1848. James Hall, Esq., *Albany, State of New York, U.S.A.*
1851. Professor James D. Dana, *New Haven, Connecticut, U.S.A.*
1853. Count Alexander von Keyserling, *Raykull, Russia.*
1856. Professor Robert Bunsen, For. Mem. R.S., *Heidelberg.*
1857. Professor H. B. Geinitz, *Dresden.*
1859. Dr. Ferdinand Römer, *Breslau.*
1866. Dr. Joseph Leidy, *Philadelphia, U.S.A.*
1867. Professor A. Daubrée, For. Mem. R.S., *Paris.*
1871. Dr. Franz Ritter von Hauer, *Vienna.*
1874. Professor Alphonse Favre, *Geneva.* (*Deceased.*)
1874. Professor E. Hébert, *Paris.* (*Deceased.*)
1874. Professor Albert Gaudry, *Paris.*
1875. Professor Fridolin Sandberger, *Würzburg.*
1875. Professor F. August von Quenstedt, *Tübingen.* (*Deceased.*)
1876. Professor E. Beyrich, *Berlin.*
1877. Dr. Carl Wilhelm Gümbel, *Munich.*
1877. Dr. Eduard Suess, *Vienna.*
1879. Major-General N. von Kokscharow, *St. Petersburg.*
1879. M. Jules Marcou, *Cambridge, U.S.A.*
1879. Dr. J. J. S. Steenstrup, For. Mem. R.S., *Copenhagen.*
1880. Professor Gustave Dewalque, *Liége.*
1880. Baron Adolf Erik Nordenskiöld, *Stockholm.*
1880. Professor Ferdinand Zirkel, *Leipzig.*
1882. Professor Sven Lovén, *Stockholm.*
1882. Professor Ludwig Rütimeyer, *Basle.*
1883. Professor J. S. Newberry, *New York, U.S.A.*
1883. Professor Otto Martin Torell, *Stockholm.*
1884. Professor G. Capellini, *Bologna.*
1884. Professor A. L. O. Des Cloizeaux, For. Mem. R.S., *Paris.*
1884. Professor J. Szabó, *Pesth.*
1885. Professor Jules Gosselet, *Lille.*
1886. Professor Gustav Tschermak, *Vienna.*
1887. Professor J. P. Lesley, *Philadelphia, U.S.A.*
1887. Professor J. D. Whitney, *Cambridge, U.S.A.*
1888. Professor Pierre J. van Beneden, *Louvain.*
1888. Professor Eugène Renevier, *Lausanne.*
1888. Baron Ferdinand von Richthofen, *Berlin.*
1889. Professor Ferdinand Fouqué, *Paris.*
1889. Marquis Gaston de Saporta, *Aix-en-Provence.*
1889. Professor Karl Alfred von Zittel, *Munich.*
1890. Professor Heinrich Rosenbusch, *Heidelberg.*
1890. Herr Dionys Stur, *Vienna.*

## LIST OF

# THE FOREIGN CORRESPONDENTS

## OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1890.

Date of Election.

1863. Dr. F. Senft, *Eisenach.*
1864. Dr. Charles Martins, *Montpellier.* (*Deceased.*)
1866. Professor Victor Raulin, *Montfaucon d'Argonne.*
1866. Baron Achille de Zigno, *Padua.*
1874. Professor Igino Cocchi, *Florence.*
1874. M. Gustave H. Cotteau, *Auxerre.*
1874. Dr. T. C. Winkler, *Haarlem.*
1877. Professor George J. Brush, *New Haven, U.S.A.*
1879. M. Édouard Dupont, *Brussels.*
1879. Dr. Émile Sauvage, *Boulogne-sur-Mer.*
1880. Dr. Melchior Neumayr, *Vienna.* (*Deceased.*)
1880. Professor Alphonse Renard, *Ghent.*
1881. Professor E. D. Cope, *Philadelphia, U.S.A.*
1882. Professor Louis Lartet, *Toulouse.*
1882. Professor Alphonse Milne-Edwards, *Paris.*
1884. Dr. Charles Barrois, *Lille.*
1884. M. Alphonse Briart, *Morlanwelz.*
1884. Professor Hermann Credner, *Leipzig.*
1884. Baron C. von Ettingshausen, *Grätz.*
1884. Dr. E. Mojsisovics von Mojsvár, *Vienna.*
1885. Professor G. Lindström, *Stockholm.*
1885. Dr. A. G. Nathorst, *Stockholm.*
1886. Professor J. Vilanova y Piera, *Madrid.*
1887. Senhor J. F. N. Delgado, *Lisbon.*
1887. Professor A. Heim, *Zurich.*
1887. Professor A. de Lapparent, *Paris.*
1888. Professor W. C. Brögger, *Christiania.*
1888. M. Charles Brongniart, *Paris.*
1888. Professor Edward Salisbury Dana, *New Haven, U.S.A.*
1888. Professor Anton Fritsch, *Prague.*
1888. M. Ernest Van den Broeck, *Brussels.*
1889. Professor G. K. Gilbert, *Washington, U.S A.*
1889. M. A. Michel-Lévy, *Paris.*
1889. Dr. Hans Reusch, *Christiania.*
1889. Professor Antonio Stoppani, *Milan.* (*Deceased.*)
1889. M. R. D. M. Verbeek, *Padang, Sumatra.*
1890. M. Gustave F. Dollfus, *Paris.*
1890. Herr Felix Karrer, *Vienna.*
1890. Professor Adolph von Könen, *Göttingen.*
1890. M. Friedrich Schmidt, *St. Petersburg.*

# AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE "DONATION FUND"

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., &c.

"To promote researches concerning the mineral structure of the earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,"—"such individual not being a Member of the Council."

1831. Mr. William Smith.
1835. Dr. G. A. Mantell.
1836. M. Louis Agassiz.
1837. Capt. T. P. Cautley. Dr. H. Falconer.
1838. Sir Richard Owen.
1839. Professor C. G. Ehrenberg.
1840. Professor A. H. Dumont.
1841. M. Adolphe T. Brongniart.
1842. Baron L. von Buch.
1843. M. Élie de Beaumont. M. P. A. Dufrénoy.
1844. Rev. W. D. Conybeare.
1845. Professor John Phillips.
1846. Mr. William Lonsdale.
1847. Dr. Ami Boué.
1848. Rev. Dr. W. Buckland.
1849. Professor Joseph Prestwich.
1850. Mr. William Hopkins.
1851. Rev. Prof. A. Sedgwick.
1852. Dr. W. H. Fitton.
1853. M. le Vicomte A. d'Archiac. M. E. de Verneuil.
1854. Sir Richard Griffith.
1855. Sir H. T. De la Beche.
1856. Sir W. E. Logan.
1857. M. Joachim Barrande.
1858. Herr Hermann von Meyer. Mr. James Hall.
1859. Mr. Charles Darwin.
1860. Mr. Searles V. Wood.
1861. Professor Dr. H. G. Bronn.
1862. Mr. R. A. C. Godwin-Austen.
1863. Professor Gustav Bischof.
1864. Sir R. I. Murchison.
1865. Dr. Thomas Davidson.
1866. Sir Charles Lyell.
1867. Mr. G. Poulett Scrope.
1868. Professor Carl F. Naumann.
1869. Dr. H. C. Sorby.
1870. Professor G. P. Deshayes.
1871. Sir A. C. Ramsay.
1872. Professor J. D. Dana.
1873. Sir P. de M. Grey-Egerton.
1874. Professor Oswald Heer.
1875. Professor L. G. de Koninck.
1876. Professor T. H. Huxley.
1877. Mr. Robert Mallet.
1878. Dr. Thomas Wright.
1879. Professor Bernhard Studer.
1880. Professor Auguste Daubrée.
1881. Professor P. Martin Duncan.
1882. Dr. Franz Ritter von Hauer.
1883. Dr. W. T. Blanford.
1884. Professor Albert Gaudry.
1885. Mr. George Busk.
1886. Professor A. L. O. Des Cloizeaux.
1887. Mr. J. Whitaker Hulke.
1888. Mr. H. B. Medlicott.
1889. Professor T. G. Bonney.
1890. Professor W. C. Williamson.
1891. Professor J. W. Judd.

## AWARDS

OF THE

## BALANCE OF THE PROCEEDS OF THE WOLLASTON "DONATION FUND."

1831. Mr. William Smith.
1833. Mr. William Lonsdale.
1834. M. Louis Agassiz.
1835. Dr. G. A. Mantell.
1836. Professor G. P. Deshayes.
1838. Sir Richard Owen.
1839. Professor C. G. Ehrenberg.
1840. Mr. J. De Carle Sowerby.
1841. Professor Edward Forbes.
1842. Professor John Morris.
1843. Professor John Morris.
1844. Mr. William Lonsdale.
1845. Mr. Geddes Bain.
1846. Mr. William Lonsdale.
1847. M. Alcide d'Orbigny.
1848. { Cape-of-Good-Hope Fossils. M. Alcide d'Orbigny.
1849. Mr. William Lonsdale.
1850. Professor John Morris.
1851. M. Joachim Barrande.
1852. Professor John Morris.
1853. Professor L. G. de Koninck.
1854. Dr. S. P. Woodward.
1855. Drs. G. and F. Sandberger.
1856. Professor G. P. Deshayes.
1857. Dr. S. P. Woodward.
1858. Mr. James Hall.
1859. Mr. Charles Peach.
1860. { Professor T. Rupert Jones. Mr. W. K. Parker.
1861. Professor A. Daubrée.
1862. Professor Oswald Heer.
1863. Professor Ferdinand Senft.
1864. Professor G. P. Deshayes.
1865. Mr. J. W. Salter.
1866. Dr. Henry Woodward.
1867. Mr. W. H. Baily.
1868. M. J. Bosquet.
1869. Mr. W. Carruthers.
1870. M. Marie Rouault.
1871. Mr. R. Etheridge.
1872. Dr. James Croll.
1873. Professor J. W. Judd.
1874. Dr. Henri Nyst.
1875. Mr. L. C. Miall.
1876. Professor Giuseppe Seguenza.
1877. Mr. R. Etheridge, Jun.
1878. Professor W. J. Sollas.
1879. Mr. S. Allport.
1880. Mr. Thomas Davies.
1881. Dr. R. H. Traquair.
1882. Dr. G. J. Hinde.
1883. Mr. John Milne.
1884. Mr. E. Tulley Newton.
1885. Dr. Charles Callaway.
1886. Mr. J. S. Gardner.
1887. Mr. B. N. Peach.
1888. Mr. J. Horne.
1889. Mr. A. Smith Woodward.
1890. Mr. W. A. E. Ussher.
1891. Mr. R. Lydekker.

# AWARDS OF THE MURCHISON MEDAL

AND OF THE

## PROCEEDS OF "THE MURCHISON GEOLOGICAL FUND,"

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, Bart., F.R.S., F.G.S.

"To be applied in every consecutive year in such manner as the Council of the Society may deem most useful in advancing geological science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any inquiries bearing upon the science of geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of geological science."

1873. Mr. William Davies. *Medal.*
1873. Professor Oswald Heer.
1874. Dr. J. J. Bigsby. *Medal.*
1874. Mr. Alfred Bell.
1874. Professor Ralph Tate.
1875. Mr. W. J. Henwood. *Medal.*
1875. Professor H. G. Seeley.
1876. Mr. A. R. C. Selwyn. *Medal.*
1876. Dr. James Croll.
1877. Rev. W. B. Clarke. *Medal.*
1877. Professor J. F. Blake.
1878. Dr. H. B. Geinitz. *Medal.*
1878. Professor C. Lapworth.
1879. Professor F. M'Coy. *Medal.*
1879. Mr. J. W. Kirkby.
1880. Mr. R. Etheridge. *Medal.*
1881. Professor A. Geikie. *Medal.*
1881. Mr. F. Rutley.
1882. Professor J. Gosselet. *Medal.*
1882. Professor T. Rupert Jones.
1883. Professor H. R. Göppert. *Medal.*
1883. Mr. John Young.
1884. Dr. H. Woodward. *Medal.*
1884. Mr. Martin Simpson.
1885. Dr. Ferdinand Römer. *Medal.*
1885. Mr. Horace B. Woodward.
1886. Mr. W. Whitaker. *Medal.*
1886. Mr. Clement Reid.
1887. Rev. P. B. Brodie. *Medal.*
1887. Mr. Robert Kidston.
1888. Professor J. S. Newberry. *Medal.*
1888. Mr. E. Wilson.
1889. Professor James Geikie. *Medal.*
1889. Mr. Grenville A. J. Cole.
1890. Professor Edward Hull. *Medal.*
1890. Mr. E. Wethered.
1891. Professor W. C. Brögger. *Medal.*
1891. Rev. R. Baron.

# AWARDS OF THE LYELL MEDAL

AND OF THE

## PROCEEDS OF THE "LYELL GEOLOGICAL FUND,"

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE

SIR CHARLES LYELL, Bart., F.R.S., F.G.S.

The Medal "to be given annually" (or from time to time) "as a mark of honorary distinction as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,"—"not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions at the discretion of the Council for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper shall be written."

1876. Professor John Morris. *Medal.*
1877. Dr. James Hector. *Medal.*
1877. Mr. W. Pengelly.
1878. Mr. G. Busk. *Medal.*
1878. Dr. W. Waagen.
1879. Professor Edmond Hébert. *Medal.*
1879. Professor H. A. Nicholson.
1879. Dr. Henry Woodward.
1880. Mr. John Evans. *Medal.*
1880. Professor F. A. von Quenstedt.
1881. Sir J. W. Dawson. *Medal.*
1881. Dr. Anton Fritsch.
1881. Mr. G. R. Vine.
1882. Dr. J. Lycett. *Medal.*
1882. Rev. Norman Glass.
1882. Professor C. Lapworth.
1883. Dr. W. B. Carpenter. *Medal.*
1883. Mr. P. H. Carpenter.
1883. M. E. Rigaux.
1884. Dr. Joseph Leidy. *Medal.*
1884. Professor Charles Lapworth.
1885. Professor H. G. Seeley. *Medal.*
1885. Mr. A. J. Jukes-Browne.
1886. Mr. W. Pengelly. *Medal.*
1886. Mr. D. Mackintosh.
1887. Mr. Samuel Allport. *Medal.*
1887. Rev. Osmond Fisher.
1888. Professor H. A. Nicholson. *Medal.*
1888. Mr. A. H. Foord.
1888. Mr. T. Roberts.
1889. Professor W. Boyd Dawkins. *Medal.*
1889. M. Louis Dollo.
1890. Professor T. Rupert Jones. *Medal.*
1890. Mr. C. Davies Sherborn.
1891. Professor T. McKenny Hughes. *Medal.*
1891. Dr. C. J. Forsyth-Major.
1891. Mr. G. W. Lamplugh.

## AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially "as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much."

1877. Professor O. C. Marsh.
1879. Professor E. D. Cope.
1881. Dr. C. Barrois.
1883. Dr. Henry Hicks.
1885. Professor Alphonse Renard.
1887. Professor Charles Lapworth.
1889. Mr. J. J. Harris Teall.
1891. Dr. G. M. Dawson.

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## AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

"The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science."

1880. Purchase of microscope.
1881. Purchase of microscope lamps.
1882. Baron C. von Ettingshausen.
1884. Dr. James Croll.
1884. Professor Leo Lesquereux.
1886. Dr. H. J. Johnston-Lavis.
1888. Museum.
1890. Mr. W. Jerome Harisron.

ESTIMATES *for*

INCOME EXPECTED.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| Compositions | | | | 189 | 0 | 0 |
| Due for Arrears of Admission-fees | 94 | 10 | 0 | | | |
| Admission-fees, 1891 | 252 | 0 | 0 | | | |
| | | | | 346 | 10 | 0 |
| Due for Arrears of Annual Contributions | | | | 100 | 0 | 0 |
| Annual Contributions, 1891, from Resident Fellows, and Non-residents, 1859 to 1861 | | | | 1660 | 0 | 0 |
| Annual Contributions in advance | | | | 35 | 0 | 0 |
| Dividends on Consolidated $2\frac{3}{4}$ per Cents. | | | | 101 | 1 | 4 |
| Dividends on London and North-Western Railway 4 per cent. Consolidated Preference Stock | | | | 87 | 15 | 0 |
| Dividends on London and South-Western Railway 4 per cent. Consolidated Preference Stock | | | | 78 | 0 | 0 |
| Sale of Quarterly Journal, including Longman's account | 165 | 0 | 0 | | | |
| Sale of Geological Map, including Stanford's account | 10 | 0 | 0 | | | |
| Sale of Transactions, Library-catalogue, Ormerod's Index, Hochstetter's "New Zealand," and List of Fellows | 5 | 0 | 0 | | | |
| | | | | 180 | 0 | 0 |
| | | | | £2777 | 6 | 4 |

THOMAS WILTSHIRE, TREAS.

*4th February,* 1891.

*the Year* 1891.

## EXPENDITURE ESTIMATED.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| House Expenditure: | | | | | | |
| Taxes | 23 | 0 | 0 | | | |
| Fire-insurance | 15 | 0 | 0 | | | |
| Gas | 30 | 0 | 0 | | | |
| Fuel | 30 | 0 | 0 | | | |
| Furniture and Repairs | 100 | 0 | 0 | | | |
| House-repairs and Maintenance | 20 | 0 | 0 | | | |
| Annual Cleaning | 15 | 0 | 0 | | | |
| Washing and Sundries | 35 | 0 | 0 | | | |
| Tea at Meetings | 16 | 0 | 0 | | | |
| | | | | 284 | 0 | 0 |
| Salaries and Wages: | | | | | | |
| Assistant Secretary | 250 | 0 | 0 | | | |
| Acting Editor | 30 | 0 | 0 | | | |
| Assistant Librarian and Assistant Clerk | 260 | 0 | 0 | | | |
| House Steward | 105 | 0 | 0 | | | |
| Housemaid | 40 | 0 | 0 | | | |
| Errand Boy | 48 | 0 | 0 | | | |
| Charwoman and Occasional Assistance | 25 | 0 | 0 | | | |
| Attendants at Meetings | 8 | 0 | 0 | | | |
| Accountant's Fee | 10 | 10 | 0 | | | |
| | | | | 776 | 10 | 0 |
| Official Expenditure: | | | | | | |
| Stationery | 28 | 0 | 0 | | | |
| Miscellaneous Printing | 35 | 0 | 0 | | | |
| Postages and other Expenses | 90 | 0 | 0 | | | |
| | | | | 153 | 0 | 0 |
| Gratuities to Assistant Librarian and Assistant Clerk | | | | 50 | 0 | 0 |
| Library | | | | 220 | 0 | 0 |
| Museum | | | | 5 | 0 | 0 |
| Publications: | | | | | | |
| Geological Map | 15 | 0 | 0 | | | |
| Quarterly Journal | 1000 | 0 | 0 | | | |
| ,, ,, Commission, Postage, and Addressing | 100 | 0 | 0 | | | |
| List of Fellows | 35 | 0 | 0 | | | |
| Abstracts, including Postage | 110 | 0 | 0 | | | |
| | | | | 1260 | 0 | 0 |
| Balance in favour of the Society | | | | 28 | 16 | 4 |
| | | | | £2777 | 6 | 4 |

*Income and Expenditure during the*

RECEIPTS.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| Balance in Bankers' hands, 1 January, 1890 | 238 | 5 | 0 | | | |
| Balance in Clerk's hands, 1 January, 1890 | 10 | 19 | 1 | | | |
| | | | | 249 | 4 | 1 |
| Compositions | | | | 315 | 0 | 0 |
| Arrears of Admission-fees | 100 | 16 | 0 | | | |
| Admission-fees, 1890 | 352 | 16 | 0 | | | |
| | | | | 453 | 12 | 0 |
| Arrears of Annual Contributions | | | | 101 | 17 | 0 |
| Annual Contributions for 1890, viz.: | | | | | | |
| Resident Fellows | 1650 | 12 | 0 | | | |
| Non-Resident Fellows | 14 | 3 | 6 | | | |
| | | | | 1664 | 15 | 6 |
| Annual Contributions in advance | | | | 35 | 14 | 0 |
| Dividends on $2\frac{3}{4}$ p. c. Consolidated Stock | 170 | 10 | 5 | | | |
| ,, L. & N. W. Railway Stock | 39 | 0 | 0 | | | |
| ,, L. & S. W. Railway Stock | 39 | 0 | 0 | | | |
| | | | | 248 | 10 | 5 |
| Taylor & Francis: Advertisements in Journal, Vol. 45 | | | | 7 | 1 | 4 |
| Publications: | | | | | | |
| Sale of Journal, Vols. 1–45 | 98 | 8 | 2 | | | |
| ,, Vol. 46 * | 76 | 8 | 7 | | | |
| Sale of Library Catalogue | 1 | 5 | 0 | | | |
| Sale of Geological Map | 27 | 2 | 5 | | | |
| Sale of Ormerod's Index | 2 | 8 | 6 | | | |
| Sale of Hochstetter's "New Zealand" | 0 | 6 | 0 | | | |
| Sale of Transactions | 1 | 11 | 8 | | | |
| Sale of List of Fellows | 0 | 7 | 6 | | | |
| | | | | 207 | 17 | 10 |
| Sale of £5230 17*s.* 6*d.* Consolidated $2\frac{3}{4}$ per cent. Stock @ $98\frac{1}{4}$ | | | | 5139 | 6 | 9 |

| | £ | s. | d. |
|---|---|---|---|
| *Due from Messrs. Longmans, in addition to the above, on Journal, Vol. 46, &c. | 57 | 10 | 10 |
| Due from Stanford on account of Geological Map | 2 | 2 | 6 |

We have compared this statement with the Books and Accounts presented to us, and find them to agree.

(Signed) F. G. HILTON PRICE, J. F. BLAKE, } *Auditors.*

24*th January*, 1891.

£8422 18 11

*Year ending* 31*st December,* 1890.

EXPENDITURE.

| | | | | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|---|---|---|
| **House Expenditure:** | | | | | | | | | |
| Taxes | | | | 21 | 10 | 0 | | | |
| Fire-insurance | | | | 15 | 0 | 0 | | | |
| Gas | | | | 26 | 1 | 7 | | | |
| Fuel | | | | 25 | 10 | 6 | | | |
| Furniture and Repairs | | | | 24 | 4 | 4 | | | |
| House-repairs | | | | 17 | 18 | 9 | | | |
| Annual Cleaning | | | | 13 | 12 | 1 | | | |
| Washing and Sundries | | | | 30 | 3 | 3 | | | |
| Tea at Meetings | | | | 16 | 0 | 0 | | | |
| | | | | | | | 190 | 0 | 6 |
| **Salaries and Wages:** | | | | | | | | | |
| Assistant Secretary | | | | 144 | 1 | 7 | | | |
| Acting Editor | | | | 60 | 0 | 0 | | | |
| Assistant Librarian and Assistant Clerk | | | | 240 | 0 | 0 | | | |
| House Steward | | | | 105 | 0 | 0 | | | |
| Housemaid | | | | 40 | 0 | 0 | | | |
| Errand Boy | | | | 47 | 15 | 6 | | | |
| Charwoman | | | | 23 | 2 | 9 | | | |
| Attendants at Meetings | | | | 8 | 0 | 0 | | | |
| Accountant's Fee | | | | 10 | 10 | 0 | | | |
| | | | | | | | 678 | 9 | 10 |
| **Official Expenditure:** | | | | | | | | | |
| Stationery | | | | 22 | 4 | 0 | | | |
| Miscellaneous Printing | | | | 26 | 11 | 2 | | | |
| Postages and other Expenses | | | | 90 | 14 | 10 | | | |
| | | | | | | | 139 | 10 | 0 |
| Gratuity voted to Mrs. Dallas | | | | | | | 50 | 0 | 0 |
| Library | | | | | | | 192 | 16 | 7 |
| Museum | | | | | | | 3 | 0 | 7 |
| **Publications:** | | | | | | | | | |
| Geological Map | | | | 25 | 12 | 8 | | | |
| Journal, Vols. 1–45 | | | | 9 | 14 | 8 | | | |
| ,, Vol. 46 | 867 | 18 | 1 | | | | | | |
| ,, ,, Commission, Postage, and Addressing | 108 | 17 | 3 | | | | | | |
| | | | | 976 | 15 | 4 | | | |
| List of Fellows | | | | 34 | 2 | 2 | | | |
| Abstracts, including Postage | | | | 108 | 5 | 11 | | | |
| Ormerod's Index | | | | 21 | 5 | 0 | | | |
| Transactions | | | | 0 | 2 | 11 | | | |
| | | | | | | | 1175 | 18 | 8 |
| Investment in £100 Consolidated $2\frac{3}{4}$ per cent. Stock, @ $97\frac{1}{2}$ | | | | 97 | 12 | 6 | | | |
| Investment in £2000 L. & N. W. Railway 4 per cent. Consolidated Pref. Stock, @ $127\frac{1}{2}$ | | | | 2575 | 13 | 0 | | | |
| Investment in £250 L. & N. W. Railway 4 per cent. Consolidated Pref. Stock, @ $127\frac{3}{4}$ | | | | 322 | 17 | 6 | | | |
| Investment in £2000 L. & S. W. Railway 4 per cent. Consolidated Pref. Stock, @ $126\frac{7}{8}$ | | | | 2563 | 2 | 3 | | | |
| | | | | | | | 5559 | 5 | 3 |
| Balance in Bankers' hands, 31 Dec. 1890 | | | | 415 | 15 | 3 | | | |
| Balance in Clerk's hands, 31 Dec. 1890 | | | | 18 | 2 | 3 | | | |
| | | | | | | | 433 | 17 | 6 |
| | | | | | | | £8422 | 18 | 11 |

THOMAS WILTSHIRE, *Treasurer.*

## "Wollaston Donation Fund." Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| Balance at Bankers', 1 January, 1890 | 22 | 9 | 3 | Cost of striking Gold Medal awarded to Prof. W. C. Williamson | 10 | 10 | 0 |
| Dividends on the Fund invested in $2\frac{3}{4}$ per cent. Consolidated Stock | 29 | 1 | 4 | Award to Mr. W. A. E. Ussher | 19 | 4 | 7 |
| | | | | Balance at Bankers', 31 December, 1890 | 21 | 16 | 0 |
| | £51 | 10 | 7 | | £51 | 10 | 7 |

## "Murchison Geological Fund." Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| Balance at Bankers', 1 January, 1890 | 19 | 10 | 0 | Award to Prof. E. Hull, with Medal | 10 | 10 | 0 |
| Dividends on the Fund invested in London and North-Western Railway 4 per cent. Debenture Stock | 39 | 0 | 0 | " Mr. E. Wethered | 27 | 13 | 0 |
| | | | | Cost of Medal | 0 | 17 | 0 |
| | | | | Balance at Bankers', 31 December, 1890 | 19 | 10 | 0 |
| | £58 | 10 | 0 | | £58 | 10 | 0 |

## "Lyell Geological Fund." Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| Balance at Bankers', 1 January, 1890 | 51 | 9 | 0 | Award to Prof. T. Rupert Jones, with Medal | 42 | 0 | 0 |
| Dividends on the Fund invested in Metropolitan $3\frac{1}{2}$ per cent. Stock | 68 | 12 | 0 | " Mr. C. D. Sherborn | 25 | 11 | 0 |
| | | | | Cost of Medal | 1 | 1 | 0 |
| | | | | Balance at Bankers', 31 December, 1890 | 51 | 9 | 0 |
| | £120 | 1 | 0 | | £120 | 1 | 0 |

## "Barlow-Jameson Fund." Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| Balance at Bankers', 1 January, 1890 | 37 | 17 | 2 | Balance at Bankers', 31 December, 1890 | 51 | 5 | 6 |
| Dividends on the Fund invested in $2\frac{3}{4}$ per cent. Consolidated Stock | 13 | 8 | 4 | | | | |
| | £51 | 5 | 6 | | £51 | 5 | 6 |

## "Bigsby Fund." Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| Balance at Bankers', 1 January, 1890 | 4 | 6 | 7 | Balance at Bankers', 31 December, 1890 | 9 | 18 | 7 |
| Dividends on the Fund invested in $2\frac{3}{4}$ per cent. Consolidated Stock | 5 | 12 | 0 | | | | |
| | £9 | 18 | 7 | | £9 | 18 | 7 |

## Valuation of the Society's Property; 31st December, 1890.

| Property. | £ | s. | d. | £ | s. | d. | | £ | s. | d. |
|---|---|---|---|---|---|---|---|---|---|---|
| Due from Longman & Co., on account of Journal, vol. xlvi. &c. | | | | 57 | 10 | 10 | Balance in favour of the Society | 9603 | 14 | 8 |
| Due from Stanford on account of Map | | | | 2 | 2 | 6 | | | | |
| Balance in Bankers' hands, 31 Dec. 1890 | | | | 415 | 15 | 3 | | | | |
| Balance in Clerk's hands, 31 Dec. 1890 | | | | 18 | 2 | 3 | | | | |
| Funded Property:— | | | | | | | | | | |
| Consolidated $2\frac{3}{4}$ per Cents. at 95 | 3769 | 2 | 6 | 3580 | 13 | 10 | | | | |
| London & North-Western Railway 4 per cent. Consolidated Pref. Stock at 126. | 2250 | 0 | 0 | 2835 | 0 | 0 | | | | |
| London & South-Western Railway 4 per cent. Consolidated Pref. Stock at 125. | 2000 | 0 | 0 | 2500 | 0 | 0 | | | | |
| Arrears of Admission-fees (considered good) | | | | 94 | 10 | 0 | | | | |
| Arrears of Annual Contributions (considered good) | | | | 100 | 0 | 0 | | | | |
| [*N.B.—The above does not include the value of the Collections, Library, Furniture, and stock of unsold Publications.*] | | | | £9603 | 14 | 8 | | £9603 | 14 | 8 |

THOMAS WILTSHIRE, *Treas.*

*24th January*, 1891.

## Award of the Wollaston Medal.

In presenting the Wollaston Medal to Prof. J. W. Judd, F.R.S., the President addressed him as follows:—

Professor Judd,—

The Council have awarded to you the Wollaston Medal in recognition of the important services rendered by you to Geological science, especially in the department of Petrography. In recalling for a moment the value and extent of these services, I am reminded that, after showing your powers by an excellent paper on the strata of the Lincolnshire Wolds, you began your geological career in the Geological Survey under Murchison, and that you had thus a favourable opportunity of acquiring that practical acquaintance with the details of geological structure which can in no way be so thoroughly mastered as by actual patient mapping. Your volume on the "Geology of Rutland" proved how well you had profited by the advantages which your official duties afforded you. From the Jurassic rocks of England, which you had studied in minute detail, you were led to undertake the investigation of those of Scotland, which you succeeded in reducing to order, bringing them into closer relationship with their equivalents in the southern part of the United Kingdom.

It was in the course of those northern expeditions that you were drawn from the field of stratigraphy into the study of volcanic rocks, to which you have since devoted so large a part of your time and thought, and in the study of which you have journeyed far and wide in this country, and have extended your travels to the islands of the Mediterranean. The problems presented by these rocks in the field led you to seek the aid of the microscope, and to enter upon a course of distinguished petrographical research. I trust that the award of this Medal will be received by you as a mark of the estimation in which your work is held by the Society in whose Quarterly Journal most of it has been published.

Prof. Judd, in reply, said:—

Mr. President,—

It is a source of legitimate gratification to the student of science when a favourable judgment on his efforts is pronounced by his contemporaries and fellow-workers. In receiving this highly-prized

mark of your approval, I would fain forget for one moment, if that were possible, how far the work—of which you have spoken in such graceful terms—falls in amount below my hopeful anticipations of the past, how it fails to reach the standard of excellence of my cherished ideals. Any value which that work may be found to possess is undoubtedly due, in great part, to the fostering care of the Society which to-day so generously crowns my labours. To the Geological Society, in its corporate capacity, I am indebted for the reception and publication of the results of my studies ; to individuals composing that Society I owe more than I can ever express, for kind sympathy, warm encouragement, and friendly aid; and to both Council and members I shall always be deeply grateful alike for helpful suggestion and discriminating criticism.

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## Award of the Wollaston Donation Fund.

The President then presented the Balance of the Wollaston Fund to Richard Lydekker, Esq., B.A., F.G.S., saying :—

Mr. Lydekker,—

The Council has awarded to you the proceeds of the Wollaston Donation Fund in recognition of the value of your numerous contributions to Vertebrate Palæontology. We trust that you will continue these investigations and that, whether they appear in the publications of this Society or elsewhere, the results, like those which have preceded them, may tend to the steady advancement of our favourite science.

Mr. Lydekker, in reply, said :—

Mr. President,—

The particular branch of Palæontology to which my own studies have been more especially directed is one which, from its nature, is so beset with difficulties that it is very apt to lead to misgivings as to whether any real good results from its pursuit. The assurance conveyed by the honour that the Council of the Society has conferred upon me, that such work as I have been able to do is not unappreciated, is therefore very gratifying.

Although circumstances have rendered it almost imperative that I

should devote my time to literary work rather than to original scientific research, yet I still hope to do something in the latter field.

Please accept, Sir, on the behalf of the Council, my thanks for the mark of distinction that they have bestowed upon me.

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## Award of the Murchison Medal.

In handing the Murchison Medal, awarded to Professor W. C. Brögger, of Christiania, to J. J. H. Teall, Esq., M.A., F.R.S., for transmission to the recipient, the President spoke as follows:—

Mr. Teall,—

The Council has awarded the Murchison Medal to Professor W. C. Brögger, of Christiania, and in asking you to transmit it to him I will request you also to convey to him an expression of the high estimation in which we hold his researches among the older rocks of Scandinavia. He is remarkable among the geologists of Europe for the great range of his acquirements. If we were to read only his descriptions of the Silurian fauna of Southern Norway we should, doubtless, believe him to be essentially a palæontologist. If we looked over his maps and sections of the Christiania district, we should think of him rather as an admirable stratigrapher and cartographer. If, again, we began with his account of the eruptive rocks and their zone of contact-metamorphism, we should conclude that his chief studies must have lain in microscopic and chemical petrography, of which he is so accomplished a master. Or, lastly, if we knew him only by such essays as his late paper on garnets, we should regard him as preeminently a mineralogist, gifted with rare originality. He has swept a full chord on the geological lyre, and every note sounds rich and true.

It gives me personally an especial pleasure to be the intermediary in conveying the award of the Council, for I have had the advantage of being conducted by Professor Brögger over some of his classic ground around Christiania, and I know from my own experience how accurate and exhaustive is the work; how courteous, genial, and helpful the man. He will, I trust, receive this Medal, bearing the likeness and the name of one of the great masters of British Geology, who was also a pioneer in the geology of Norway, as a pledge of our esteem and sympathy with him in the great work he

has already accomplished, and in the long and brilliant career which we hope is still in store for him.

Mr. Teall, in reply, read the following communication received by him from Prof. Brögger:—

"I beg to express my hearty gratitude for the great and completely unexpected honour conferred upon me by the Council of the Geological Society in the award of the Murchison Medal.

"The Founder of this medal, almost half a century ago, classified the Silurian rocks of the Christiania district, and pointed out their relations to the corresponding strata of Great Britain; so that, if the subsequent investigations of Norwegian geologists have furnished results of interest to the students of British Geology, this is only a slight repayment of an old debt.

"In ancient times the mountain-ranges of northern Great Britain and Norway were probably connected, and in the Quaternary period the Scandinavian ice-sheet stretched across to England and deposited boulders of Norwegian rocks, some of which were derived from the Christiania district. Now, in recent times science has rebuilt the bridges which formerly connected the two countries, inhabited by closely related peoples of the Germanic race.

"It will be an object of especial interest to me to contribute, as far as I am able, to the reconstruction of bonds of union between Great Britain and Norway, in grateful remembrance of the benefits which Norwegian geologists in general, and I myself in particular, have derived from the celebrated Geological Society of London.

"Allow me, in conclusion, to express the great satisfaction I feel at receiving this honour during the Presidency of so eminent a geologist as Dr. Archibald Geikie, who is personally acquainted with the geology of Norway."

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## Award of the Murchison Geological Fund.

The President then handed the Balance of the Murchison Geological Fund (awarded to the Rev. Richard Baron, F.L.S., F.G.S., of Antananarivo) to Wm. Topley, Esq., F.R.S., for transmission to the recipient, saying:—

Mr. Topley,—

I have to request you to transmit to the Rev. R. Baron the Balance

of the proceeds of the Murchison Geological Fund, in testimony of the interest taken by the Council in the geological work which, amid so many discouragements, he is carrying on in Madagascar. We desire him to accept this Award as a mark of our hearty sympathy and of our wish to aid him in his researches.

Mr. Topley, in reply, said:—

Mr. President,—

On behalf of Mr. Baron, who is now in Madagascar, I beg to thank the Council and yourself for the honour conferred upon him in the award of the Murchison Fund. As a Missionary in an area as yet but little known, Mr. Baron has exceptional opportunities for original research, and that he has not neglected those opportunities is evident from his papers already read to this Society and to the Linnean Society. The Award now made will, I am sure, be an incentive to further work in a most promising field of research.

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## Award of the Lyell Medal.

In presenting the Lyell Medal to Prof. T. McKenny Hughes, F.R.S., the President addressed him as follows:—

Professor Hughes,—

The Lyell Medal has this year been adjudged by the Council to you in appreciation of the value of your investigations in various departments of Geology, especially among the older rocks. Your researches in Caernarvonshire and Anglesey formed the starting-point of those later enquiries which have done so much to clear up the earlier chapters of the geological history of Wales. You have not confined yourself, however, to the rocks of any one system or period, but have ranged freely from Archæan gneiss to raised beach, hovering for a moment here and resting a little there, generally critical, almost always suggestive, and with that happy faculty of enthusiasm which, reacting on younger minds, "allures to older worlds, and leads the way."

As I place this Medal in your hands I cannot but recall the days of our early friendship, now faded so far into the dim past of life, when, as colleagues in the Geological Survey, we used to attend the meetings of this Society in Somerset House, taking seats on a back

row and gazing down upon the magnates of the science seated beneath. Little did either of us dream that the whirligig of time would eventually place us where we find ourselves to-day. It is thus no small gratification to me to be called upon to present to you this Medal, which will not only serve to mark the Society's appreciation of your work, but which will connect you by another link with the memory of our friend and master, Lyell.

Prof. Hughes, in reply, said :—

Mr. President,—

I feel that I have, as the senior, been selected to receive this high recognition of the work being carried on by the Cambridge School of Geology. I have not myself been able to offer much to the Society of late, save occasional criticism, but my colleagues, Mr. Marr and Mr. Harker, Fellows of the Society, whose opinions are regarded each year with increasing respect, the one your Secretary, the other on your Council, have from time to time contributed valuable papers, while my other colleague, Mr. Roberts, has also laid before the Society the results of important original observations made by him. The Society knows that it is chiefly to the lecture-room, the museum, and the field-classes that it must look for men to carry on its work in the future. But I must acknowledge in this respect also, that the heaviest work has fallen upon my colleagues. They know, however, that in the administration of the Department, and directly and indirectly in promoting the cause of Science, I help as far as I can. We all work well together, and I feel that they will rejoice with me now, will help to carry back the Lyell Medal in triumph to Cambridge, and will join with me in offering to the Society our warmest thanks for the honour that has been done us. We shall regard it as a stimulus to follow in the steps of the great teacher whose name is commemorated on the Medal, and try always to distinguish clearly between what is proved, what is disproved, and what remains, however plausible, "not proven."

I am glad that it has fallen to my lot to receive this honour from the hands of an old and valued friend, upon whom has fallen the mantle of Lyell, a mantle in which the warp of science and the weft of literature are so deftly interwoven.

## Award of the Lyell Geological Fund.

The President then handed one half of the Balance of the Lyell Geological Fund, awarded to Dr. C. J. Forsyth-Major, of Florence, to Dr. H. Woodward, F.R.S., for transmission to the recipient, and addressed him as follows:—

Dr. Woodward,—

In requesting you to transmit to Dr. Forsyth-Major one moiety of the Balance of the Lyell Geological Fund, I wish to express the Council's appreciation of his researches and its hope that he will continue them. He has done much to increase our knowledge of the Pliocene Mammalia of the Val d'Arno, and he has recently extended his explorations among the younger Tertiary deposits of the Eastern Mediterranean.

Dr. Woodward, in reply, said:—

Mr. President,—

On behalf of Dr. C. J. Forsyth-Major, I have to acknowledge the honour conferred upon him by the Council of this Society in awarding him a moiety of the Lyell Fund. The work to which Dr. Forsyth-Major has devoted his life so entirely accords with the researches and labours of Sir Charles Lyell that I cannot doubt the appropriateness of this Award.

Dr. Forsyth-Major has devoted many years to the elucidation of the Pleistocene and Pliocene mammalian faunas of the Val d'Arno and Northern Italy, and his numerous memoirs attest the value and accuracy of his work. Lately he has devoted two years to the exploration of the Pliocene fauna of the Island of Samos, and has obtained thence two very important collections (at present only partially examined)—one now in the Geneva Museum, the other in the British Museum (Natural History), Cromwell Road. Among these are a large number of forms specifically identical with the mammals from the equivalent deposits of Pikermi in Attica, Baltavar in Hungary, and Maragha in Persia; and also several new types of much interest as showing a former wider distribution for existing forms.

It is Dr. Forsyth-Major's hope to spend the early summer months in London, to complete his descriptions of these fossil remains, which your Award will doubtless assist him in doing.

He writes as follows:—

"Would you kindly transmit to the President and Council of the Geological Society my grateful acknowledgments of the honour conferred upon me, which I value so much the more as coming from a scientific body of my own country, to which, owing to the fact that my family resides abroad, I have become nearly a stranger.

"If I rightly understand the intention of the Council, this Award is given less as a mark of their approval of what I have already done than as an incentive to future labours.

"In my palæontological work I have striven to follow the example of one of the masters of our science, the late Dr. Hugh Falconer, devoting myself more to the collecting of facts and observations than to their speedy publication. This reserve seems to be imposed upon us even more in our day than in that of Dr. Falconer's."

In presenting the other half of the Balance of the Lyell Geological Fund to G. W. Lamplugh, Esq., F.G.S., the President addressed him as follows:—

Mr. Lamplugh,—

The Council, in awarding to you one half of the proceeds of the Lyell Geological Fund, desires to assure you of the estimation in which it holds your work, and of the pleasure it will derive from their further prosecution. Your researches among the Glacial deposits of Yorkshire have been followed with much interest, and we have rejoiced in the enthusiasm which not only carried you through these labours at home, but which impelled you to seek the solution of some of your difficulties by journeying to the far-distant shores of British Columbia. Your investigation of the Speeton Clay affords a striking example of how our knowledge may be corrected and extended by the patient labours of an observer resident on the spot which he has to examine. I hope you will accept this Award with the best wishes of the Council and of the Society.

Mr. Lamplugh, in reply, said:—

Mr. President,—

That I should have been selected by the Council to receive this Award affords me the greatest encouragement, since it comes to me as a token that my geological work, in spite of its narrow and local character, has after all a certain value.

It is scarcely possible that anyone who has any sympathy what-

ever with nature should spend much time on the Yorkshire coast without becoming more or less of a geologist, and for my own part I drifted almost unconsciously into these studies in my boyhood, and have ever since found therein my happiest and healthiest recreation. My pleasure in them is now redoubled by this proof that the time so happily spent has also been spent usefully.

I thank you, and hope that, as a coastguard in the service of science, I may still occasionally be able to send to headquarters reports which may contain some items of interest.

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## Award of the Bigsby Medal.

The President then handed the Bigsby Medal, awarded to Dr. Geo. M. Dawson, F.G.S., of Ottawa, to Dr. Hicks, F.R.S., for transmission to the recipient, and addressed him as follows:—

Dr. Hicks,—

In asking you to transmit the Bigsby Medal to Dr. George M. Dawson, I request you to convey to him at the same time an assurance of how fully the Council appreciates the value of his researches into the geological structure of Canada, and how cordially we hope that he may live long to prosecute the explorations which have shed so much lustre on the Geological Survey of his native country.

Dr. Hicks, in reply, read the following communication, received by him from Dr. Dawson:—

"Mr. President,—

"I have to express my high appreciation of the honour which you and the Council of the Geological Society have conferred upon me in the award of the Bigsby Medal.

"I regret that my official duties at the present time render it impossible for me to be present in person at the Anniversary Meeting to assure the Society of the high esteem in which I hold this mark of recognition.

"My field of geological work has lain chiefly in the farther Western, and as yet imperfectly known, portions of the Dominion of Canada, and much of the work itself has been of an exploratory character, and only occasionally, and then to a limited extent, precise or finished. Work of this class, though necessary in the first

instance, and possessed of the special interest attaching to any virgin field, must suffer by comparison with that obtained in the investigation of smaller areas, and carried on under more favourable conditions. It is thus all the more gratifying and encouraging to me that such results as I may have been able to obtain should be deemed worthy of the recognition of the Society.

"I may be pardoned for alluding to the fact that some of the earliest work in Canadian Geology is due to the personal efforts of the distinguished Founder of this Medal, in whose very footsteps it has at times been my privilege to follow. This, with the pleasant remembrance of advantages derived in former years from personal intercourse with Dr. Bigsby, and kindly advice received from him, tend to enhance, if possible, the sense of gratification felt by me in learning that my name has been added to the roll of those considered worthy to receive the Bigsby Medal."

## THE ANNIVERSARY ADDRESS OF THE PRESIDENT, A. GEIKIE, LL.D., F.R.S.

GENTLEMEN,—

From recounting the successful labours of those who are our living fellow-workers, and whom we are delighted to-day to honour, we have on this anniversary occasion to turn to the sadder task of noting how far our ranks have been thinned by death during the year that is past. Our losses have been numerous and heavy, for they include distinguished leaders both abroad and at home.

Foremost among the names which now disappear from our list of Foreign Members stands that of EDMOND HÉBERT. The son of an old soldier who cultivated a small farm, he was born in 1812 at Villefargeau, a village on the outskirts of Auxerre, in Burgundy. His school career at the College of Auxerre proved to be so remarkably brilliant, that instead of being bred as a farmer, he was allowed to make his way to the École Normale. Coming up to Paris for this purpose, he found it needful to teach Latin, and even for a time to turn schoolmaster, in order to provide himself with funds for continuing his education. At the École Normale he rose by sheer talent to the position of influence for which his abilities marked him out, becoming sub-director of scientific studies and lecturer on geology. Afterwards he was appointed to the Chair of Geology at the Sorbonne, where he had ample scope for the development of his rare gift of attracting and interesting others in his own field of study.

In two distinct and important ways, Hébert conferred lasting benefits on the science of his time. In the first place, as a brilliant and enthusiastic teacher, he gathered around him a school of energetic and able geologists, whom by his encouragement and example he stimulated to investigation in France and in foreign countries. His pupils are to be found filling Chairs of Geology all over France, and carrying on the traditions and the spirit of the geological department of the Sorbonne.

In the second place, as an accurate observer and clear writer, he has enriched geological literature with a series of luminous memoirs, which will remain his most fitting and enduring monument. Among these essays we recall with pleasure that in which he recorded the results of his visit to the Isle of Wight in 1851, and correlated the

Tertiary deposits of England with those of France; likewise the memoir in which he compared our English Chalk with that of his own country. His chief stratigraphical labours lay among the Tertiary and Cretaceous formations of the Paris basin. We owe to his sagacious observations the subdivision of the Chalk into zones, and the employment of these zones in tracing out the folds into which the younger Secondary rocks have been thrown. He extended his researches among the Cretaceous formations from the downs of England to the shores of the Mediterranean and the Black Sea. But there was hardly a section of the geological record which he had not studied, and to the interpretation of which he did not contribute some important suggestion. At one time he might be found comparing the Jurassic succession of France with that of Scandinavia; at another time discussing the pre-Cambrian and older Palæozoic rocks. His clear insight and calm judgment were especially valuable in the treatment of questions which have given rise to much controversy. And in this respect I may particularly refer to his deliberate verdict, reiterated in 1886, as to the relative positions of the Cambrian and Silurian systems.

Hébert's position was freely acknowledged to be that of the leading geologist in his native country. He was chosen a member of the Institute of France, and honorary dean of the Faculty of Sciences. He received the ribbon of Commander of the Legion of Honour. He was three times elected President of the Geological Society of France. Many foreign Societies did themselves honour by enrolling him among their associates. Our own Society made him a Foreign Correspondent in 1863, and a Foreign Member in 1874, while in 1879 it conferred on him the Lyell Medal. He died on the 4th April, 1890, at the age of 78 years.

By the death of ALPHONSE FAVRE, Switzerland has been deprived of one of her most illustrious men of science, who worthily held aloft the torch of Alpine exploration first kindled by Bénédict de Saussure, and handed on by Escher von der Linth and Studer. Born in 1815 amid scenery that presents vividly to the eye some of the great facts of geology, he was early led to study this science, and he pursued its cultivation with so much ardour and success, that in 1844 he became Professor of Geology in the Academy of Geneva. In 1840 he set himself to the serious investigation of the complicated structure of the Central Alps, and next year established the important fact that the apparent infra-position of Jurassic lime-

stones, with belemnites, to Carboniferous strata with Coal-measure plants, was not a violation of the accepted laws of stratigraphical succession, but could be satisfactorily accounted for by a complete inversion of the rocks. With indomitable perseverance he laboured at his arduous task until at last in 1862 he was able to publish his geological map of the Mont-Blanc region, followed five years later by three volumes of explanatory text. He wrote also a work in two volumes descriptive of the geology of the Canton of Geneva, which appeared in 1880.

One of his most important labours was the contribution made by him to glacial geology in 1884, when his great map of the old glaciers of the northern slopes of the Alps appeared. This work, familiar to every one who has studied the glaciation of Switzerland, brings graphically before the eye the size and range of the former snowfields and glaciers, and the curious way in which the ice-drainage differed from the present river-drainage of the same region.

On the death of Studer, Favre succeeded to the direction of the Geological Survey of Switzerland, the maps of which were then almost completed, the last sheet making its appearance in 1888. In his later years, though enfeebled by failing health, he continued to interest himself in his favourite studies. Geologists will remember with pleasure his experiments in illustration of the plication and rupture of rocks in the process of mountain-making, and the striking photographs by which he made them known. He was elected a Foreign Correspondent of this Society in 1863 and a Foreign Member in 1874—by a curious coincidence the same two years in which these honours were bestowed on Hébert. He died on the 11th of July last.

Antonio Stoppani has long been known as one of the most voluminous writers among the geologists of Italy. His early labours included a study of the Triassic and Infra-liassic rocks of the north of Italy, and he has since continued these researches. Appointed to the Professorship of Geology in the Royal Technical Institute of Milan, he made it his duty to enlarge his acquaintance with the whole range of geological formations, and to read widely in his favourite science. He had considerable skill in arranging and describing geological facts and speculations, as he showed by producing his 'Corso di Geologia,' a work in three volumes, of which the first appeared in 1871, and the others two years later. His

most important publication was his large monograph in four quarto volumes on the Palæontology of Lombardy, begun in 1858 and completed in 1881, with the cooperation of Prof. Cornalia and Prof. Meneghini. Better known, perhaps, to geologists generally is the volume on the Neozoic era, published in 1881, in which he discussed the glaciation of the Italian Alps, and the condition of the Italian peninsula during Pleistocene times. He was elected a Foreign Correspondent of our Society in 1889. At the time of his death, which took place on the 1st January last, in the 66th year of his age, he was President of the Italian Society of Natural Sciences.

Turning now to the home-list, first and most memorable among our losses during the bygone year is that caused by the death of our esteemed and distinguished Foreign Secretary. We have already formally expressed our deep regret at this event and our recognition of the value of the long and devoted service rendered to the Society by our late colleague. But I am sure I shall carry with me the entire sympathy of every Fellow if I dwell for a little on what our friend was to us and to others, what he did for science, and why we shall long mourn his departure from our midst.

Warington W. Smyth was born in 1817 at Naples, where his maternal grandfather, Mr. Thomas Warington, was British Consul. His father, Admiral W. H. Smyth, F.R.S., spent many years in the Admiralty Survey of the Mediterranean. He wrote papers on astronomical and geographical subjects, as well as separate works on Sicily and the Mediterranean, which marked him out as one of the most scientific naval officers of his time. The son was sent home to be educated in this country, and was placed at Westminster and Bedford Schools, subsequently entering at Trinity College, Cambridge. Endowed with a constitution of rare vigour, and a passion for active exercise, he threw himself with ardour into the sports of the University, formed one of the winning University Crew in 1839, and as "head of the river" rowed with such energy as to be nicknamed "the steam-engine."

Leaving Cambridge with a travelling bachelorship, he spent more than four years in journeying over a large part of Europe, extending his rambles into Asia Minor, the borders of Kurdistan, Syria, and Egypt. Having already begun to look with interest on minerals and rocks, he made it one of his main objects in this prolonged tour

to visit mines and to see for himself how the various ores occur in nature. His sojourn in Germany and Austria gave him the opportunity of making the acquaintance of such men as Humboldt, Von Buch, Von Dechen, Naumann, Haidinger, and Von Hauer. At one time he is found attending lectures on Mineralogy; at another time he is to be seen exploring coal-fields or descending silver-mines, or pushing his way through salt-works, or ransacking bone-caves. Again we hear of him among the rugged sunburnt rocks of Monte Cristo or encamped with Waltershausen near the summit-snows of Etna. A winter on the Nile is followed by a more adventurous ramble through Palestine and Northern Syria to Aleppo and the Upper Tigris. This prolonged absence abroad not only gave him a wide experience of practical mining-matters, but afforded him opportunities of cultivating that familiarity with foreign habits and foreign languages which made him in the end an ideal Foreign Secretary for a Geological Society.

Returning to this country in 1844 he made the acquaintance of De la Beche, Director-General of the Geological Survey, who, with his intuitive perception of the merits of a good man for his purpose, soon engaged him as Mining-geologist on the staff of the Survey. In that capacity Smyth made explorations in England and Wales and in Ireland, besides mapping some districts with his own hand. When a few years later (1851) the School of Mines was organized, he was appointed Lecturer on Mining and Mineralogy, and he continued to give his mining lectures down to the very end. His wide knowledge of all that relates to the extraction of minerals from the crust of the earth led to his being called on to undertake many additional duties. He was appointed Chief Mineral Inspector to the Office of Woods and Forests, and also Mineral Inspector to the Duchy of Cornwall. Besides acting as adviser to the Crown in all mining questions, he was often requested to give his services on Committees and Commissions. He was appointed Chairman of the Royal Commission which, in 1879, was formed to enquire into the subject of accidents in mines, and he had the main share in drawing up the voluminous Report of the seven years of enquiry spent in this laborious and important investigation. It was more especially in recognition of this service that he received the honour of knighthood in 1887.

All through life one of the busiest of men, he yet had the happy art, by quietly keeping his toils in the background, to seem to be possessed of ample leisure ready to be placed at the service of any

friend who wanted to talk with him or any student who sought his advice. Always on the outlook for additions to his knowledge and ever ready to impart to others what he had gained himself, he seldom cared to publish what he knew. Early in life he wrote an account of his wanderings in the East, which appeared in 1854 under the title of "A Year with the Turks." A few memoirs by him, chiefly on mineral veins and mining localities, found a place in the "Memoirs of the Geological Survey" and the "Transactions of the Geological Society of Cornwall." He wrote also occasional articles, such as that on Mining in Ure's "Dictionary," likewise a small but standard Treatise on Coal and Coal-mining, of which the seventh edition appeared last year.

Up to within the last year or two of his life he showed but little sign of advancing age. His step seemed as light, his eye as keen, his mind as active as in his early days. But a weakness of the heart began to make itself felt and forced him to abridge some of his more fatiguing duties. He came to the evening gathering of the Royal Society last summer, where he looked perhaps better than he had done for some time previously, and talked in his old cheerful way. Next morning, 19th June, sitting in his library with his students' examination-papers before him, he quietly passed away, dying as he had lived, in harness.

It is not from the bulk, nor even from the intrinsic importance of his published work, that the services of Sir Warington Smyth to the cause of science are to be estimated. More efficient and widespread, perhaps, than the influence of his writings, was that of his personal example and teaching. Every year he sent forth a body of students trained by him in the habits of careful observation, of cautious induction, and of manly outspoken honesty which were his own distinguishing characteristics. These men, scattered all over the world, carried with them the impress of his instruction, and no more unalloyed pleasure ever came to him than the tidings that his pupils had done him credit in the career on which he had started them.

Among the beneficent influences of his honoured life we Fellows of the Geological Society count those not the least which he exerted for us during his long and intimate association with us. He joined our body in 1845. For more than thirty years he served on our Council, filling successively the offices of Secretary, Vice-President, and President, and for the last seventeen years sitting at the Council-table as Foreign Secretary. In every capacity in which he could be useful to us he was ever ready to give us the benefit of

his ripe experience and wise counsels. We mourn his death with sincere sorrow, and though "the sweet benefit of time" will doubtless soften our regret, we shall never cease to remember with affectionate regard the distinguished colleague and the generous-hearted friend whom we have lost in Warington Smyth.

Samuel A. Adamson was a well-known and widely-esteemed geologist of the Midlands, who, receiving his early training under Professor Green at Leeds, did good service to the cause of science by spreading an interest in the progress of geology. He took an active part in the affairs of the local scientific societies and became a Fellow of this Society in 1877. He specially devoted his attention to the Carboniferous rocks and the Drift phenomena of his own neighbourhood.

Samuel H. Beckles will be remembered in the history of Geology chiefly for the important work which he did in unearthing the oldest known Mammalian remains from the rocks of the Purbeck group. In 1856, following up a previous discovery by Mr. Brodie, he succeeded in bringing to light twelve or more species of unquestionably warm-blooded quadrupeds, together with remains of many reptiles, several insects, and some freshwater shells. Students of Lyell's "Elements of Geology" will remember how prominent a place these discoveries occupied in the geological literature of the day. Mr. Beckles had previously given some attention to the Wealden strata, and had published a few papers regarding them and the bird-like footprints found in them. He joined this Society in 1854, and his energy and skill in the exploration of the Purbeck mammalian deposit were recognized by his election into the Royal Society in 1859. He died in August of last year.

Henry Bowman Brady was born at Gateshead in 1835. The son of a medical practitioner, he was led to interest himself in the relations between medicine and chemistry, and while still a lad started in business as a pharmaceutical chemist in Newcastle. His thoroughly scientific habit of mind showed itself from the first in his career. He devoted himself with ardour to the scientific development of the practical branch of chemistry which he had adopted, served for many years on the Council of the Pharmaceutical Society, and contributed much by his efforts and influence to further its objects. But he had strong natural-history tastes also, which early

in life he was enabled to gratify amidst the marine fauna of the North Sea. He occupied himself in studying dredgings off the Northumberland coast and from the Dogger Bank. By degrees he was led to give himself up to the investigation of the Foraminifera as his special life-work, and he became in the end one of our chief authorities on these lowly organisms.

He published many original and valuable papers on recent forms of Foraminifera, concluding with his great Monograph in the Reports of the 'Challenger' Expedition. But of especial interest to us as geologists are his researches among the fossil forms. It was he who first made known the nature of those curious spherical bodies in the Carboniferous Limestone which he named *Saccammina Carteri*. It was he, too, who first described the nummulite-like *Archædiscus* from the Lower-Carboniferous rocks of this country, and who showed that a true nummulite (*Nummulina*) occurs in the Carboniferous Limestone of Belgium presenting the most astonishing resemblance in structural detail to its still living allies. He wrote also on the Foraminifera of the Crag; but many of his papers on the recent forms had important geological bearings, and well merit the study of the geologist.

His father belonged to the Society of Friends, and though he himself renounced the quaint garb and other outward signs of that body, he retained the frank honesty and homely kindliness so characteristic of it. His success in business was such, that in 1876 he felt himself able to retire, and to devote himself entirely to scientific research. But his health, never robust, sadly interfered with his progress, and compelled him to winter abroad. He undertook long journeys into milder climes, but carried his love of science with him, and lost no opportunity of increasing his store of knowledge, and enlarging his acquaintance with the subject which he had made so entirely his own. A happy illustration of the way in which he used these opportunities of foreign travel is furnished by the only communication he made to this Society—a "Note on the so-called 'Soapstone' of Fiji." This is a soft post-Tertiary rock, reaching in one place to 700 feet above the sea, in which his practised eye detected 92 species of Foraminifera, 87 of which are still living in the neighbouring seas, and he inferred that the deposit accumulated at a depth of 100 to 200 fathoms, so that the sea-floor had been elevated to at least that amount.

Mr. Brady became a Fellow of this Society in 1864. He was elected into the Royal Society in 1874, and was likewise a Fellow

of the Linnean and Zoological Societies. The winter of 1889-90 was spent by him in Egypt, but the change proved less beneficial than previous sojourns abroad. He determined this last winter to remain at Bournemouth, where, surrounded with his materials, he hoped to do some more useful work for science. But the severe weather told on his already enfeebled constitution, and he was carried off by inflammation of the lungs on the 10th of January last.

By the death of William Davies, who, after a lingering illness, passed away on the 13th inst., at the age of 77, Vertebrate Palæontology has lost one of its most accomplished students. His retiring disposition, and his devotion for so many years to the official duties discharged by him at the British Museum, made his name less familiarly known to geologists than his extensive knowledge and important services would have justified. His published work is of comparatively small extent, but of great merit. He was not ambitious of distinction, for he regarded the acquisition of scientific knowledge and the happiness of communicating it to others as reward enough. As far back as eighteen years ago the Society recognized his merits, and the unselfish readiness with which he placed his almost unrivalled special knowledge at the service of all who sought his help, by conferring on him the first award of the Murchison Medal.

Handel Cossham was born in 1824. His connexion with mining operations in the Bristol coal-field led him to interest himself in geology, and in the midst of a busy life he found time to put on record some interesting facts relating to the structure of our Coal-measures. The existence of what we now know as thrust-planes had been previously pointed out by Mr. J. McMurtrie, in what was called the "Radstock slide-fault," in the southern part of the Bristol coal-field. Mr. Cossham proved that a similar structure occurred in the northern part, where the "Great Vein" and other seams of coal have been disrupted and driven bodily over each other, in a manner which, though almost unique in this country, closely resembles the inversions and dislocations of the Belgian coal-fields. At the time of his death Mr. Cossham had in hand a paper describing further discoveries in regard to this structure. In his later years he sat as member of Parliament for Bristol, and devoted much of his time to political questions, on which he was a voluminous pamphleteer.

John Gunn was born on 9th October, 1801, and died on 28th May of last year. His long life of eighty-eight years was marked by a singular ardour of temperament, sterling honesty of purpose, unselfish devotion, and transparent goodness of heart. Even in boyhood and youth, at a time when the literature of the natural sciences was neither so ample nor so accessible as it has since become, he contrived to gratify his strong desire to make himself acquainted with the geological history of his native county. Succeeding his father in 1841 in the rectory of Irstead and Barton Troy, he was enabled to spend his leisure in his favourite pursuit. The remarkable Forest Bed of the Norfolk Coast, which had attracted his notice in his boyish years, now supplied him with materials for earnest research. He became an untiring collector of its vertebrate remains, and a diligent student of its structure and history, till in the end he was acknowledged to be the chief authority regarding it.

But, though unwearied and enthusiastic in the acquisition of knowledge, he was reluctant to publish his observations; consequently the wide extent and accuracy of his information were hardly known, save to those who came into personal contact with him. To them he would ungrudgingly impart all he knew. Of the materials thus supplied by him, a good deal found its way into print in the publications of others, from which geologists gradually came to appreciate how much their knowledge of the Pliocene deposits of this country was due to him.

With characteristic generosity he presented to the Norfolk and Norwich Museum the fine series of fossils collected by him from the Forest Bed, and by this gift, as well as by the example of his own enthusiasm, he did much to encourage the study of geology in Norfolk. After having been in the service of the Church for forty years, he resigned his living in 1869, and in the end quitted the ministry on the ground that he found he could no longer hold some of the doctrines which his clerical office required him to teach. It could have been no ordinary strength of conviction and integrity of moral purpose that led a man verging on seventy years of age to relinquish the "place of his birth, the scenes of his childhood and of a mature and happy life, where almost every tree and shrub had been planted by himself, and, above all, to part from parishioners between whom and himself there ever had existed a most cordial feeling of good-will."

Though Mr. Gunn published little, we are indebted to him for an

interesting sketch of the geology of Norfolk, which appeared in 1864 in White's "History and Directory of the County." This essay, reprinted for private circulation, reached a fourth edition in 1883, and its author's last labour was bestowed on the revision and extension of the work, with a view to publication. Geologists will be glad to learn that the task which he did not live to complete has been undertaken, as a tribute to his memory, under the able editorship of Mr. H. B. Woodward, whose personal friendship for the author, and intimate knowledge of Norfolk geology, admirably qualify him for giving us a fitting memorial of John Gunn.

Thomas Field Gibson, who died at the close of last year, though not a professed geologist, was a Fellow of our Society for 43 years, and maintained a friendly intercourse with many of the more prominent geologists of his day. Born as far back as 1803, before the Society had been instituted, he was an eyewitness of the infancy and early youth of geology in this country, and his death breaks one of the few remaining living links that connect us with the heroic time of our science. Joining his father's business, that of a silk manufacturer in London, he soon showed his breadth of culture by taking an active part in the establishment of the London Institution in Finsbury Circus and of the School of Design. His knowledge and capacity were recognized by his being selected as one of the Royal Commissioners for the first Great Exhibition in 1851, and he continued to retain his place on the Commission until his death. During the prime of his life, the house which he had at Sandown in the Isle of Wight was a frequent meeting-place of geologists—Fitton, De la Beche, Edward Forbes, and others. For the last twenty years he lived at Tunbridge Wells, maintaining his interest in our doings until the infirmities of age prevented him from attending our meetings. He served on the Council of the Society in the years 1855–58.

Thomas Grainge Hurst was born in London in 1824, and at an early age moved into the north of England, where he received the education of a mining engineer. Throughout his life he was practically connected with collieries, and took an active share in their management. His professional pursuits brought him into personal contact with the structure of the northern coal-fields, and he took advantage of his opportunities to study the variations of the coal-seams. A paper by him communicated to the North of England

Institute of Mining Engineers gives a good account of some peculiarities of the Tyne Low-Main coal-seam. He died on July 21st, 1890.

DAVID MILNE-HOME, who died in September last, at the age of eighty-five, was a country gentleman in Berwickshire, who married the heiress of another extensive property, and who might, therefore, have been thought likely to devote his life to country pursuits and interests. Like many eldest sons of old Scottish families, he studied law and was called to the bar, where he practised for some years. But his large estates eventually required much of his time and personal supervision, and he relinquished his legal pursuits, retaining, however, his town house in Edinburgh. From an early period in his life he had interested himself in geology. At the age of 32 he presented to the Royal Society of Edinburgh a remarkably able essay on the Midlothian coal-field, which was published in that Society's "Transactions," and has taken its place as a standard work of reference for the subject of which it treats. He likewise gave a geological account of Roxburghshire, and contributed an essay to the voluminous literature on the Parallel Roads of Glen Roy. His more recent exertions in geology had chiefly been devoted to the observation and registration of boulders scattered over the surface of Scotland. He was the convener of the committee appointed by the Royal Society of Edinburgh to investigate this subject, and himself compiled the ten Reports in which the committee gave an account of its labours. He took much interest in meteorology, and one of his chief occupations during the last ten or fifteen years of his life was to further in every way he could devise the work and usefulness of the Scottish Meteorological Society, of the Council of which he was Chairman.

ROBERT WILLIAM MYLNE, born in 1816, was elected into this Society in 1848. Himself the son of an eminent engineer, he chose the calling of architect and civil engineer, and soon distinguished himself by applying geological science to the practice of his profession. He paid special attention to the connexion between geological structure and water-supply, and his position as engineer for important waterworks gave him opportunities for showing the value of a knowledge of the practical applications of geology. He thus acquired a large practice as consulting engineer in matters relating to well-sinking, the construction of reservoirs, and drainage. Though he published little in the way of original scientific work, what he

did produce was so admirable as to raise regret that he never found occasion to do more. His "Map of the Geology and Contours of London and its Environs," which appeared in 1856, when he had reached his fortieth year, was a work of the most painstaking research, and is now one of the classics in the geology of the South of England. It was followed two years later by his "London, Geological—Waterworks and Sewers," and subsequently by his smaller "Geological Map of London and Environs." His reputation as a geological engineer secured his election into the Royal Society in 1860, and gave him entry into the scientific life of London, while his business habits led to his being chosen to fill various offices of honour and trust, such as the Treasurership of the Smeatonian Society of Civil Engineers and the duties of a Governor of Bridewell and Bethlehem Hospitals.

No figure has been for more than forty years more familiar in this Society than Mylne's, and none, in spite of a certain somewhat formal mannerism, more generally welcome. He served repeatedly on the Council, while his position for so many years as Treasurer of the Geological Club kept him in the heart of the life and work of the Society, and brought him into friendly touch with the active students and the leaders of geology. We shall long remember the deliberation of his announcements from the Treasurer's Chair, and the quiet humorous sallies that every now and then broke out from underneath this outward solemnity. There was, however, a side of his nature which, though it could not appear on these occasions and would, indeed, never have been suspected by those who only casually met him, ought to be borne in mind if we wish to form and preserve a just idea of his singular personality. He was the last of a long line of architects and engineers. His ancestors for many successive generations had held a foremost place in their profession in Scotland, and had built many of the bridges, mansions, and public edifices in that kingdom. To this day one of the most prominent inscriptions on the exterior of Holyrood Palace—"Ro. Mylne"—records under whose superintendence that royal dwelling was repaired in the reign of Charles II. Our late friend and associate inherited house-property near the northern capital, which, though in itself of comparatively little value, he prized because it had come to him through a line of professional men to which he was proud to belong. Much of his time during the last years of his life was spent in reading and arranging the voluminous series of letters, accounts, and other papers that bore witness to the industry and success of his

forefathers. With pious care he used to visit and keep in due repair the interesting sepulchral monument of his family in the old churchyard of the Greyfriars at Edinburgh. We can picture the satisfaction with which he would read the inscription, still clean and sharp, that records the virtues of his ancestor, John Milne, who died in 1667 :—

> " Rare man he was, who could unite in one,
> Highest and lowest occupation;
> To sit with statesmen, councillor to kings,
> To work, with tradesmen, in mechanick things.
> Reader, John Milne, who maketh the fourth John
> And, by descent, from father unto son,
> Sixth master mason to a royal race
> Of seven successive Kings, sleeps in this place."

Mylne was naturally and justly proud of this lineage; but under his exterior of stiffness and reserve there lay hidden a vein of tender sentiment, and he would now and then express his deep regret that no son of his would carry on the work and traditions of his family. He died July 2nd, 1890.

The name of GEORGE WAREING ORMEROD has long been a household word among us. It is therefore with more than common regret that we have to record his death on the 6th of January of the present year at the advanced age of eighty years. After practising law for some years in Manchester, he went to reside at Chagford, in South Devon, but for the last twenty years made his home at Teignmouth. He has communicated various papers to our Journal on such subjects as the Cheshire Salt-field, the rock-basins in the Dartmoor granite, and papers on the geology of the South-west of England, besides numerous contributions to the " Transactions " of the Devonshire Association. His memoir on the Salt-district was an important addition to the geological literature of this country.

But it is by his Classified Index to our publications that his name has been most widely known. What geologist engaged in the study of the voluminous literature of his science has not again and again had cause to congratulate the Society and himself that a man of leisure, possessing the requisite wide acquaintance with geology as well as the power of methodical and convenient arrangement, should have been found willing to devote his time to the task of constructing an orderly and easily consulted guide to the contents of our "Transactions," "Proceedings," and "Quarterly Journal"? Two editions of the work have appeared and three supplements, of which the third, published only last year, may be regarded as its author's latest gift to the Society.

William John Stephens joined our ranks in 1883. He held a leading place among the men of science in New South Wales, where he filled the office of Professor of Geology in the University of Sydney. He took an active share in the institution and work of the Linnean Society of the colony, of which, at the time of his death, he was President.

I reserve for final notice a name which will awaken many pleasant but saddened memories—that of William Sweetland Dallas. Among the heavy losses which the Society has sustained during the past year there is none that has so profoundly affected our life and work as his death. For some two-and-twenty years his tall handsome person has been the most familiar figure within our walls. Always at his post, with a pleasant smile of welcome, ever ready with assistance from his large treasures of knowledge and experience, knowing more intimately than any one else the affairs and traditions of the Society, proud of its history and keenly sensitive for its scientific reputation, he had come to be looked upon as a kind of *genius loci*—the living embodiment of the Society's aims and work. While his wide range of acquirement gained him the respect not of our Fellows only, but of the great body of naturalists in this country, his genial kindly ways gave him a sure place in the heart of every one who was ever brought into much close personal contact with him.

Born in London in 1824, it was among the hills and woods to the north of this city that he showed in early boyhood the tastes that were to fashion his future career. He devoted himself with ardour to entomology, not as a mere butterfly-gatherer, but with increasing zeal as a true naturalist. His father's death made it needful for him to take early to some calling, and as his boyish pursuits offered no prospect of a livelihood, he was placed in a house of business in the City. But before long the restraints and associations of such a life became too irksome for him, and he found his way into the reading-room of the British Museum, where, in his zeal to have a work of reference in his favourite department of science, he actually copied out in his own clear handwriting the whole of Fabricius's colossal "Entomologia Systematica," a work in 2677 octavo pages, adding a coloured figure of each genus in its proper place. Enthusiasm and industry of so marked a kind soon attracted the notice of his seniors, and especially of Dr. John Edward Gray of the British Museum. The young man was encouraged to contribute papers to

the Entomological Society, and in his 25th year he became a Fellow of the Linnean Society. For some ten or twelve years thereafter he remained in London preparing lists of insects for the British Museum and writing various excellent compilations, among which his "Natural History of the Animal Kingdom" has had a wide sale, and has done much to spread a sound knowledge of zoology through the country. In 1858 he became Curator of the Yorkshire Philosophical Society's Museum in York, and moved thither with his wife and family, carrying with him also the chain of literary undertakings which had bound him so closely to his desk in London. Besides discharging the duties of his curatorship, he continued his contributions to the "Westminster Review," the "Annals and Magazine of Natural History," and the "Philosophical Magazine," and took an active and helpful share in the scientific life of which York was the centre.

In 1868 Mr. Dallas was selected to fill the post of Assistant Secretary to this Society. How admirably he discharged the multifarious and onerous duties of this responsible office has been gratefully acknowledged by the Council and by the Society. For 22 years he continued to serve us with a single-heartedness, intelligence, and zeal, for which we must ever remain his debtors. Even when the hand of death was already almost visibly upon him, he still struggled to do his duty, coming to our meetings, taking his customary part in our proceedings, and only retiring to his home to die. He was struck down by paralysis and died on May 29th, 1890.

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The onward march of Geology has led to the gradual accumulation of much knowledge regarding the varying phases of volcanic action and the distribution of volcanoes over the surface of the globe. Yet those students of the science who have made themselves most familiar with this constantly increasing mass of information will most readily admit that we are still very far from having arrived at any adequate philosophy of vulcanism. Before such a philosophy can be framed we shall need not only to undertake the comprehensive and exhaustive study of the phenomena of active volcanoes which the manifold appliances of modern science now render possible, but also to ascertain as far as may be what has been the history of volcanic action in the geological past. Modern volcanoes are the descendants of a long succession of ancestors, and we shall never fully comprehend the processes of which they are the result and evidence until we

have contrived, in some measure at least, to follow the stages of evolution through which the present condition of volcanic energy over the surface of the earth has been reached.

An investigation of this chronological nature must evidently start from a definitely ascertained stratigraphical base. Until the true order of succession of the rocks has been determined, it is impossible to make any satisfactory collation of the geological history which they chronicle. In this country, thanks in large measure to the labours of Fellows of our Society, the general stratigraphy has been so carefully worked out that probably no part of the earth's surface, of the same extent, has had its geological annals so well deciphered. Moreover, it has been our good fortune here to find the geological record marvellously complete. Undoubtedly we meet here and there with blanks in the chronicle, which must be supplied from elsewhere; but there are probably few areas of corresponding size on the face of the globe where such blanks are so few and unimportant.

But not only is our general stratigraphical series remarkably full; it includes a succession of volcanic rocks of altogether unrivalled continuity and variety. Placed on the edge of a continent and the margin of a great ocean-basin, the site of Britain has lain along that critical border-zone where volcanic energy is most active and continuous. Its geological records have accordingly preserved the memorials of volcanic eruptions from pre-Cambrian down to Older Tertiary time. Some of these memorials have been studied in minute detail, and with the general characters of the rest we are more or less familiar. The time, however, seems now to have come when an attempt may be made to present a general outline of the whole volcanic history of the region. Such is the task on which I have for some time been engaged, and the subject seems to possess sufficient importance to be worthy of being laid before the Society as the theme of the present Address.

Without entering into detailed descriptions which would be out of place on such an occasion as the present, I shall endeavour to portray in broad outline what seem to me to have been the leading characteristics of volcanic action during each great geological period, beginning with the most ancient records yet discovered. But so full and varied are the volcanic chronicles of our area that even such an outline, if it were to embrace the whole series of events, from the earliest to the latest, would extend to so great a length as to task the patience and endurance of even the most sympathetic listener.

I propose at present, therefore, to deal only with the earlier half of the story, and to trust to your kind favour for another opportunity of telling the remainder of my tale.

It will be generally admitted that our knowledge of the rocks of the earth's crust older than the Cambrian system is still exceedingly vague and imperfect. We speak of them as "pre-Cambrian" or "Archæan," as if they represented a definite section of geological time, comparable to that denoted by one of the Palæozoic systems. Yet it is obvious that under these names we include a most multifarious series of rocks which represent not one but probably many and widely separated periods of geological history. We cannot suppose that the Cambrian fauna betokens the first beginnings of organic being upon our planet. On the contrary, it must have belonged to a time when invertebrate life had already reached such a stage of advancement and differentiation that various leading types had appeared which have descended, in some cases with generic identity, down to our own day. There must have been a long pedigree to the Annelids, Crustaceans, Brachiopods, Gasteropods, and Cephalopods of the oldest known fossiliferous rocks. And somewhere on the earth's surface we may yet hope to find the stratified deposits in which the remains of some of the progenitors of these early tribes have been preserved.

Unfortunately, the older layers of the terrestrial crust, where they might have been looked for at the surface, have suffered sorely from the mutations of the geological past. They seem in large measure to have been either so effaced by denudation, or so altered by metamorphism, as to be no longer satisfactorily decipherable. But underneath the most ancient rocks, which, though now often crystalline, may be regarded as of sedimentary origin, and wherein traces of organic remains may still be looked for, lie coarse, massive gneisses which preserve all over the world a singular sameness of structure and composition. What might be found below these gneisses no man can say. They are the oldest rocks of which we yet know anything, and whatsoever may be our theory of their origin we must, at least for the present, start from them as the fundamental platform of the terrestrial crust.

The present confused nomenclature of the oldest rocks is only a faithful reflection of the vagueness of our knowledge of the geological relations of these ancient formations. The term "pre-Cambrian" has no doubt been, and may still be, a convenient designation for that un-

defined and imperfectly known portion of the geological record which underlies the Cambrian system. But it is obviously too indefinite for purposes of precise stratigraphical classification. It unites a vast succession of rocks differing widely from each other in structure and age, and possessing, indeed, only the one common character of being older than the Cambrian age. To class together, for example, under one common name, the massive gneisses of the north-west of Scotland and the well-bedded tuffs and grits below the Llanberis Slates, is as misleading as it would be to put the Llanberis Slates and the Stonesfield Slate together, because they are both pre-Cretaceous.

We need a more definite series of names for the rock-groups that underlie our Palæozoic formations, or at least we should agree to apply more precisely the names already in use. "Pre-Cambrian" and "Archæan," for example, are often employed as synonymous terms. The former word may be retained as a convenient adjective, to denote that the rocks to which it is applied are older than Cambrian time. But we do not require two epithets of equal vagueness. It would, in my opinion, be greatly conducive to clearness of definition if we resolved to restrict the term "Archæan" to the most ancient gneisses and their accompaniments. No method has yet been devised whereby the oldest gneiss of one country can be shown to be the true stratigraphical equivalent of the oldest gneiss of another. Palæontology is here of no avail, and Petrography has not yet provided us with such a genetic scheme as will enable us to make use of minerals and rock-structures as we do of fossils in the determination of geological horizons. All that can be positively affirmed regarding the stratigraphical relations of the rocks to which I would confine the term "Archæan" is that they are vastly more ancient than the oldest sedimentary and fossiliferous formations in each country where they are found. Although, taken as a whole, they present a remarkable sameness of petrographical characters in all quarters of the globe, we cannot tell whether, for example, the Lewisian gneiss of Scotland is the true equivalent of the Laurentian gneiss of Canada; undoubtedly they occupy similar stratigraphical positions, and present a close resemblance in petrographical characters.

From the very nature of the case, the name by which we designate these ancient rocks cannot possess the precise stratigraphical value of the terms applied to the fossiliferous formations. At the same time, I should guard against the implication that the name is given to a special petrographical type only found in the most ancient gneisses. When the area of observation is sufficiently extensive, we

can usually, I think, be tolerably certain that the general facies of the rocks is that which distinguishes those properly termed Archæan. But at present I should be sorry to affirm that this facies belongs entirely to the most ancient gneisses. Nor am I aware of any reason why rocks undistinguishable in composition and structure from Archæan masses may not be found in much younger formations.

Keeping, then, the term "Archæan" as a general designation for the oldest gneisses and their associated rocks, which may be still further discriminated in local types, such as the Lewisian of the Hebrides, we may separate from these any well-defined groups of sedimentary or metamorphic formations intermediate between the fundamental gneisses and the Cambrian system, such as have long been known in Canada and the United States. The tendency on the other side of the Atlantic seems, at present, rather towards the multiplication of these groups, as the details of the more ancient chapters of geological history become more fully known. But we should, I think, at least in the meantime, avoid the identification of any such primitive formations in distant unconnected regions. We may discover that in Europe, as in North America, several groups of more or less altered sedimentary strata intervene between the Cambrian slates and the Archæan gneisses, but we shall do wisely to refrain from trying to find Huronian, Keweenan, Animikie, Keewatin, Coutchiching, or Laurentian on this side of the Atlantic, until we have discovered some reliable test by which to fix their stratigraphical identity. It will be better to propose provisional local names for such well-marked groups of pre-Cambrian rocks as may be found to intervene between the Archæan platform and the base of our Palæozoic formations.

## I. ARCHÆAN.

The most ancient rocks of Britain are those termed by Murchison the "Fundamental Gneiss." They are most extensively developed in the chain of the Outer Hebrides, whence they have been termed "Hebridean," or from the island of Lewis, "Lewisian." The only districts in which they have yet been investigated in minute detail are those where, along the western borders of Sutherland and Ross-shire, they emerge from under younger formations, and where they have been carefully mapped by the Geological Survey. Until the Hebrides have been studied in the same detailed manner our knowledge of these rocks must be regarded as notably incomplete. But the investigations of the Survey, so far as they have gone, have put

us in possession of some important information regarding the nature and history of the gneiss *.

With the possible exception of a strip of ground in the Gairloch district, which includes graphite-schist, garnetiferous mica-schist, limestone, and a few other remarkable rocks, no portion of the fundamental gneiss has anywhere yielded a trace of materials that can be supposed to be of sedimentary origin. Everywhere the rock is thoroughly crystalline, and presents no structure that in any way suggests an alteration of clastic constituents. Here and there it can be traced into bands and bosses which, being either non-foliated or foliated only in a slight degree, present the ordinary characters of true eruptive masses. In Sutherland and Ross-shire these amorphous patches occur abundantly. Their external margins are not well defined, and they pass insensibly into the ordinary gneiss, the dark basic massive rocks shading off into the coarse basic gneisses, and the pegmatites of quartz and felspar which traverse them merging into bands of grey quartzose gneiss.

So far, therefore, as present knowledge goes, the Lewisian gneiss of the North-west Highlands of Scotland was originally a mass of various eruptive rocks. It has subsequently undergone a succession of deformations from enormous stresses within the terrestrial crust, which have been investigated with great care by my colleagues of the Geological Survey. But it presents structures which I venture to think are original, or at least belong to the time of igneous protrusion before the deformations took place. The alternation of rocks of different petrographical constitution suggests a succession of extravasations of eruptive materials, though it may be impossible now to determine the order in which these followed each other. In the feebly foliated bands and bosses there is a parallel arrangement of their constituent minerals or of fine and coarse crystalline layers which recalls sometimes very strikingly the flow-structure of rhyolites and other lavas. This resemblance, it will be remembered, was strongly insisted on by Poulett Scrope, who believed that the laminar structure of such rocks as gneiss and mica-schist was best explained by the supposition of the flow of a granitic magma under great pressure within the earth's crust †. For my own part I must confess that the conviction has grown upon me that these parallel structures do, in some cases, really represent traces of

* See the Report of this Survey work by Messrs. Peach, Horne, Gunn, Clough, Cadell, and Hinxman, Quart. Journ. Geol. Soc. vol. xliv. (1888) pp. 378–441.

† 'Volcanoes,' pp. 140, 283, 299.

movements in the original unconsolidated igneous masses, not yet wholly effaced by later mechanical stresses.

While there is little room for difference of opinion as to the derivation of the material of the fundamental gneiss, a wide region of mere speculation opens out when we try to picture the conditions under which the material was erupted. Some geologists have boldly advanced the doctrine that this gneiss represents the earliest crust that consolidated upon the surface of the globe. But it presents no points of resemblance to the ordinary aspect of superficial volcanic ejections. On the contrary, the thoroughly crystalline conditions even of those portions which seem most nearly to represent the original structure of the mass, the absence of anything like scoriæ or fragmental bands of any kind, and the resemblances which may be traced between parts of the gneiss and eruptive bosses of igneous rock compel us to seek the nearest analogies to the original gneiss in deep-seated masses of eruptive material. It is difficult to conceive that any rocks approaching in character to the gabbros, picrites, granulites, and other coarsely-crystalline portions of the old gneiss could have consolidated at or near the surface.

When the larger area of gneiss forming the chain of the Outer Hebrides is studied, we may obtain additional information regarding the probable original structure of the gneiss. In particular, we may look for some unfoliated cores of a more acid character, and perhaps for evidence which will show that from the igneous magma out of which the gneiss came both acid and basic layers were segregated. We may even entertain a faint hope that some trace may be discovered of superficial or truly volcanic products connected with the bosses of obviously eruptive nature. But up to the present time no indication of any such superficial accompaniments has been detected. If the bosses represent the deeper parts of columns of molten rock that flowed out at the surface as lava with discharges of fragmentary materials, all this superincumbent material had, at least in the regions which have been studied in detail, disappeared entirely before the deposition of the very oldest of our sedimentary formations.

So far, then, as the evidence now available allows a conclusion to be drawn, the fundamental gneiss reveals to us a primeval group of eruptive rocks presenting the strongest resemblance to some which in later formations are connected, as underground continuations, with bedded lavas and tuffs that were erupted at the surface. Though no direct proof has yet been obtained of true

volcanic ejections associated with the most ancient parts of the fundamental gneiss, we may be reasonably certain that the rocks there visible consolidated from igneous fusion at some depth, and we may plausibly infer that they may have been actually connected with the discharge of volcanic materials at the surface.

But the progress of investigation in the North-west Highlands has brought to light the remarkable fact that the ancient gneiss of that region is a much more complex formation than had been supposed. By a series of terrestrial stresses that came as precursors of those which in later geological times worked such great changes among the rocks of the Scottish Highlands, the original igneous bosses and sheets were compressed, plicated, fractured, and rolled out, acquiring in this process a crumpled, foliated structure. Whether or not these disturbances were accompanied by any manifestations of superficial volcanic action has not yet been determined. But we know that they were followed by a succession of dyke-eruptions, to which, for extent and variety, there is no parallel in the geological structure of this country, save in the remarkable assemblage of dykes belonging to the Tertiary volcanic period.

For the production of these dykes a series of fissures was first opened through the gneiss, having a general trend from E.S.E. to W.N.W., running in parallel lines for many miles, and so close together in some places that fifteen or twenty of them occurred within a horizontal space of one mile. The fissures were probably not all formed at the same time; at all events, the molten materials that rose in them exhibit distinct evidence of a succession of upwellings from the igneous magma below. By far the largest proportion of the dykes consists of basic materials. The oldest and most abundant of them are of plagioclase-augite rocks, which differ in no essential feature of structure or composition from the dolerites and basalts of more modern periods. They present, too, most of the broad features that characterize the dykes of later times—the central more coarsely-crystalline portion, the marginal band of finer grain, passing occasionally into what was probably a variety of tachylyte, and the transverse jointing. They belong to more than one period of emission, for they cross each other. They vary in width up to nearly 200 feet, and sometimes run with singular persistence completely across the whole breadth of the strip of gneiss in the west of Sutherland and Ross.

Later in time, and much less abundant, are certain highly basic dykes—peridotites and picrites—which cut across the dolerites in a

more nearly east-and-west direction. Last of all comes a group of thoroughly acid rocks—varieties of granite and "syenite,"—which form intrusive sheets and dykes. These dykes coincide in direction with the basalts and dolerites, but they are apt to run together into belts of granite and pegmatite 1500 feet broad.

Up to the present time no evidence has been found of any superficial outpouring of material in connexion with this remarkable series of dykes in the Lewisian gneiss. That they may have been concomitant with true volcanic eruptions may be plausibly inferred from the close analogy which, in spite of their antiquity and the metamorphism they have undergone, they still present to the system of dykes that forms a part of the great Tertiary volcanic series of Antrim and the Inner Hebrides. The close-set fissures running in a W.N.W. direction, the abundant uprise into these fissures of basic igneous rocks, followed by a later and more feeble extravasation of acid material, are features which in a singular manner anticipate the volcanic phenomena of Tertiary time.

There can be no question as to the high antiquity of these dykes. They were already in place before the advent of those extraordinary vertical lines of shearing which have so greatly affected both the gneiss and the dykes; and these movements, in turn, had long been accomplished before that ancient member of our stratified formations—the Torridon sandstone—was laid down. Though later than the original igneous material out of which the gneiss was formed, they have become so integral and essential a part of the gneiss as it now exists that they must be unhesitatingly grouped as Archæan. I may add that this interposition of dark basic dykes appears to be characteristic of the oldest gneiss far beyond the limited area of the North-west Highlands, for it may be noticed in the Archæan tracts of Donegal and Galway. With so wide an extension of the subterranean relics of volcanic energy, it is surely not too much to hope that somewhere there may have been preserved, and may still be discovered, vestiges of the superficial products of the Archæan volcanoes. Among the pebbles in the conglomerates of the Torridon sandstone there occur fragments of highly-cellular basic lavas, and of felsites, some of which are beautifully spherulitic and somewhat granophyric. These fragments may point to the existence of volcanic materials at the surface when the Torridon sandstone was deposited. Possibly they may represent some of the vanished Archæan lavas. But the time between the uprise of the Archæan dykes and the formation of that sandstone was vast enough for the advent of many

successive volcanic episodes. The pebbles may therefore be the relics of eruptions that took place long after the period of the dykes.

## II. THE YOUNGER SCHISTS.—DALRADIAN.

Between the Archæan rocks and everything of younger date there lies a complete stratigraphical break, representing, doubtless, an enormous lapse of time, which does not appear to be represented within our area by any geological formation. The reality and significance of this discordance are shown by the strongly-marked lithological contrast between the fundamental gneisses and all less ancient rocks, by the striking unconformability of even the oldest formations upon the gneiss, and by the fragments in the overlying conglomerates in these formations, which prove the gneiss to have acquired its present characteristic structures before the conglomerates were derived from it.

Of the rock-groups which were laid down between Archæan time and the oldest known portions of our Palæozoic formations, the only one of which the stratigraphical relations are abundantly clear is the Torridon sandstone. This important series of strata, at least 8000 or 10,000 feet thick, lies unconformably on the Lewisian gneiss, and is in turn covered unconformably by the fossiliferous quartzites and limestones of Durness. It was paralleled by Murchison with the Cambrian rocks of Wales; but it must be more ancient than at least the younger part of the British Cambrian system. The Durness limestones were classed by the same acute observer as Lower Silurian, and Salter pointed out the remarkable American aspect of their fossil fauna. But they have not yet been satisfactorily placed on any definite palæontological horizon among the older Palæozoic rocks of England or Wales. Most probably they are older than the Arenig group. In any view the high antiquity of the Torridon sandstone cannot be disputed. But for my present purpose this ancient formation may be passed over, for it has yielded no evidence of contemporaneous volcanic rocks.

To the east of the line of the Great Glen the Scottish Highlands display a vast succession of crystalline schists, the true stratigraphical relations of which to the Lewisian gneiss have still to be determined, but which, taken as a whole, no one now seriously doubts must be greatly younger than that ancient rock. Murchison first suggested that the quartzites and limestones found in this newer series are

the equivalents of those of Durness. This identification may yet be shown to be correct, but must be regarded as still unproved. Traces of fossils (annelid-pipes) have been found in some of the quartzites, but they afford little or no help in determining the horizons of the rocks. In Donegal, where similar quartzites, limestones, and schists are well developed, obscure indications of organic remains (corals and graptolites) have likewise been detected, but they also fail to supply any satisfactory basis for stratigraphical comparison. I have myself no doubt that the rocks are far more ancient than any that could be classed as Lower Silurian, though it is of course conceivable that portions of even Lower-Silurian strata have been caught in their plications and have undergone metamorphism. If they are claimed as pre-Cambrian, I am not aware of any better proof that can be furnished against than in favour of such a claim. They may possibly include equivalents of the Torridon sandstone as well as the Durness groups, and even portions of the upthrust Archæan platform.

This series of schists consists mainly of altered sedimentary rocks. Besides the quartzites and limestones there occur thick masses of clay-slate and other slates and schists, with bands of graphitic schist, greywacke, pebbly grit, boulder-beds, and conglomerates. Among rocks that have been so disturbed and foliated it is necessarily difficult to be always sure of the true order of succession. In the Central Highlands, however, a certain definite sequence has been found to continue as far as the ground has yet been mapped. Were the rocks always severely contorted, broken, and placed at high angles, this sequence might be deceptive and leave still uncertain the original order of deposition of the whole series. But over many square miles the angles of inclination are low, and the successive bands may be traced from hill to hill, across strath and glen, forming escarpments along the slopes and outliers on the summits, precisely as gently undulating beds of sandstone and limestone may be seen to do in the dales of Yorkshire. It is difficult to resist the belief, though it would be premature to conclude, that this obvious and persistent order of succession really marks the original sequence of deposition. In Donegal also a definite arrangement of the rock-groups has been ascertained which, when followed across the country, gives the key to its geological structure*.

The following table shows, in the apparent descending order, the

* Geol. Survey Memoirs: Geology of N.W. Donegal, 1891.

various subdivisions which have been recognized by my colleagues of the Geological Survey in the Highlands of Perthshire :—

| | |
|---|---|
| 17. Dark schist, calcareous schist, and limestone (Blair Athol). | |
| 16. Quartzite (Ben-y-Glo, Schiehallien). | |
| 15. Graphite-schist. | A great mass of epidiorite and hornblende-schist, ascending in places into the quartzite, but apparently not descending below No. 13. |
| 14. Calcareous sericite-schist. | |
| 13. Sericite-schist, with bands of quartzite (Canlochan, Glen Isla). | |
| 12. Garnetiferous mica-schist and schistose pebbly grits. | Lenticular bands of hornblende-schist. |
| 11. Limestone (Loch Tay). | Rests on a sill of hornblende-schist. |
| 10. Garnetiferous mica-schist and schistose grits. | Hornblende-schist locally abundant. |
| 9. Upper group of "green schists." | |
| 8. Garnetiferous mica-schists and schistose grits with pebbly bands. | |
| 7. Lower group of "green schists." | Hornblendic sills begin on this platform, and increase in number upwards. |
| 6. Thick group of massive grits, often abundantly pebbly, with partings of mica-schist and phyllite (Trosachs, Ben Ledi, Ben Voirlich, &c.). | |
| 5. Schists and shales, with occasional bands of pebbly grit (Loch Achray). | |
| 4. Band of conglomerate, with pebbles as large as a pigeon's egg (ridge between Lochs Achray and Ard). | |
| 3. Pale green, grey, and blue slates, with purple and red shales and bands of sandy flags (Aberfoil). | |
| 2. Pebbly rusty-coloured greywacke and grit (Pass of Leny). | |
| 1. Black shales and flags, with lenticular bands of limestone (seen against the great fault at Callander). | |

On any estimate these metamorphic rocks must be enormously thick. They are prolonged north-eastward across the Grampian range to the shores of the North Sea and Moray Firth, and south-westward through Argyllshire into the north and west of Ireland. Some of the belts of limestone are almost continuously traceable across Scotland—a distance of 250 miles; and if, as is probable, the Donegal, Mayo, and Galway limestones are a further prolongation of

the same belts, these calcareous deposits must range across a tract of not less than 420 miles. The quartzites form some of the most striking mountain-groups in the centre and south-west of Scotland, as well as in the north-west and west of Ireland. Whether we regard its area, the variety and persistence of its different members, or the scenic features which characterize it, this series of rocks is undoubtedly one of the most important in British geology.

Yet, strange to say, it has not yet received any distinctive name. We speak of the younger schists, the quartzose and gneissose flagstones, the upper gneiss, or use other more or less awkward periphrases. But there is much need of some short adjectival name which will do away with the vagueness of these various appellations, and serve at once to distinguish this vast series of metamorphic rocks. Such a name need not be a permanent addition to geological terminology, but it might at least for some time be usefully adopted as a convenient epithet until the true stratigraphical position of the rocks is definitely ascertained. In selecting a suitable geographical word, regard should be had to the extension of the rocks through both Scotland and Ireland. It is well known that from the old kingdom of Dalriada, in the north of Ireland, a colony settled in Argyllshire, and gradually acquiring dominion over the whole of Scotland, gave that kingdom its present name. I would therefore propose that the term "Dalradian" might be adopted as an appropriate and useful appellation for the crystalline schists of the north of Ireland and the centre and south-west of Scotland *.

The special feature of this great metamorphic series which requires notice on the present occasion is the evidence that, interca-

* The adjective ought properly to be 'Dalriadan,' with the accent on the second syllable; but I feel compelled to alter it into a form more consonant with English habits of pronunciation.

I regret that I have found it impossible to apply to these rocks the term 'Monian,' proposed by Professor Blake for the pre-Cambrian rocks of Anglesey. In the first place, I disclaim any idea of founding a new geological "system." Our knowledge of the rocks in question is still too vague for any such ambitious effort, and, as I have said in the text, these rocks may include representatives of Archæan gneiss, Torridon sandstone, Durness limestone, possibly even of Lower-Silurian masses. In the second place, as I shall try to show in the course of this Address, the 'Monian' system includes Archæan gneiss, younger schists like those which I class as Dalradian, and strata, volcanic and fossiliferous, of undoubtedly Bala age. It would only aggravate this confusion to apply the name to still another series of rocks in another and distant area. My object is solely to provide a convenient descriptive epithet which shall be precise and save periphrasis.

lated in the vast pile of altered sediments, there lie numerous bands of undoubtedly igneous and probably volcanic rocks. Over wide tracts of the central and south-western Highlands and of Donegal, some of the most marked and persistent rocks are sheets of diorite, epidiorite, and hornblende-schist, which were erupted as molten materials, not improbably as varieties of diabase-lava. Most of these sheets are doubtless intrusive "sills," for they can be observed to break across from one horizon to another. But some of them may possibly be contemporaneous lava-streams. A sheet may sometimes be traced for many miles, occupying the same stratigraphical platform. Such hornblendic rocks occur on a number of horizons between the great band of Ben-Voirlich grits and the Ben-y-Glo quartzite. One of the most marked of these is a sill, sometimes 200 feet thick, which underlies the Loch-Tay limestone. In Argyllshire also an abundant series of sheets of epidiorite, amphibolite, and hornblende-schist runs with the prevalent strike of the schists, grits, and limestones of that district; while similar rocks reappear in a like position in Donegal. The frequency of the association of these eruptive rocks with the limestones is worthy of remark.

Besides the sheets there occur also bosses of similar material, which in their form and their obvious relation to the sheets recall the structure of volcanic vents. They consist of hornblendic rocks, like the sheets, but usually tolerably massive, with much less trace of superinduced foliation.

But besides the obviously eruptive masses there is another abundant group of rocks which I believe furnishes important evidence as to contemporaneous volcanic action during the accumulation of the Dalradian series. Throughout the central and south-western Highlands certain zones of "green schist" have long arrested the attention of the officers of the Geological Survey. They occur more especially on two horizons (Nos. 7 and 9 of the foregoing table), but the peculiar greenish tint and corresponding mineral constituents are likewise found diffused through higher parts of the series. So much do they vary in structure and composition that no single definition of them is always applicable. At one extreme are dull green chlorite-schists, passing into a "potstone," which, like that of Trondhjem, can be cut into blocks for architectural purposes *. At the other extreme lie grits and quartzites, with a slight admixture of the same greenish-coloured constituent. Between these

* From such a rock, which crosses the upper part of Loch Fyne, the Duke of Argyll's residence at Inveraray has been built.

limits almost every stage may be met with, the proportion of chlorite or hornblende and of granular or pebbly quartz varying continually, not only vertically, but even in the extension of the same bed. The quartz-pebbles are sometimes opalescent, and occasionally larger than peas. An average specimen from one of the zones of "green schists" is found, on closer examination, to be a thoroughly schistose rock, composed of a matrix of granular quartz, through which acicular hornblende and biotite crystals, or actinolite and chlorite, are ranged along the planes of foliation.

That these rocks are essentially of detrital origin admits of no doubt. They differ, however, from the other sedimentary members of the Dalradian series in the persistence and abundance of the magnesian silicates diffused through them. The idea which they suggested to my mind some years ago was that the green colouring-matter represented fine basic volcanic dust, which had been showered out during the accumulation of ordinary quartzose, argillaceous, and calcareous sediments, and that, under the influence of the metamorphism which has so greatly affected all the rocks of the region, the original pyroxenes had suffered the usual conversion into hornblendes, chlorites, and mica. This view has occurred also to my colleagues on the Survey, and is now generally adopted by them.

Not only are these "green schists" traceable all through the central Highlands; rocks of similar character, and not improbably on the same horizons, cross Argyllshire, reappear in the north-west of Ireland, and run thence south-westward as far as this series of rocks extends. If we are justified in regarding them as metamorphosed tuffs and ashy sediments, they mark a widespread and long-continued volcanic period during the time when the later half of the Dalradian series was deposited.

A remarkable confirmation of the inference that the deposition of that series was accompanied by widespread and long-continued volcanic activity has lately been obtained in County Tyrone. Mr. Nolan, of the Geological Survey of Ireland, has described a group of green basic rocks from the north of Pomeroy, containing talcose schists and schist-breccias, sometimes presenting "all the appearance of metamorphosed conglomerates," and including hornblendic and pyroxenic masses *. On visiting that district with my colleagues in the Survey, Mr. B. N. Peach and Mr. A. McHenry, I found that it includes an undoubted core of Archæan gneiss, resembling in all

* Geol. Mag. for 1879.

essential characters the Lewisian rocks of the north-west of Scotland. This ancient ridge, however, is flanked by the local base of the Dalradian series, consisting of a group of coarse volcanic agglomerates, tuffs, and lavas, which are succeeded by and pass up into green chloritic schists and silvery mica-schists like those of the Scottish Highlands. The importance of the discovery of so distinct a volcanic group in rocks of such antiquity led me recently to pay a second visit to the district, and to follow the volcanic zone for some miles to the south-west.

The lavas are chiefly dull greenish, fine-grained, sometimes highly amygdaloidal, the amygdules consisting generally of calcite. Close to the gneiss these rocks are not foliated, but they show abundant lines of shearing, along which they assume a schistose structure. The cores of solid uncrushed rock still retain perfectly the original spherical form of the vesicles. Under the microscope they are found to be diabases, in which the lath-shaped felspars, and the augite which these penetrate, are sometimes tolerably fresh, while in other parts fibrous chlorite, granular epidote, and veins of calcite bear witness to the metamorphism which they have undergone *.

There occur also, but less abundantly in the part of the district examined by me, platy felsitic rocks which have suffered much from shearing, and consequently have acquired a fissile slaty structure.

The agglomerates are made up of angular, subangular, and rounded fragments of different lavas embedded in a matrix of similar composition. This matrix has in places become quite schistose, and then closely resembles some parts of the "green schists" already referred to. Of the embedded stones the great majority consist of various felsites which, weathering with a thick white opaque crust, are internally close-grained dull grey or even black, sometimes showing flow-structure, and of all sizes up to 8 inches in diameter or more. There are also fragments of the basic lavas. On many of the rocky hummocks no distinct bedding can be made out in the agglomerate, but in others the rock is tolerably well stratified.

The tuffs are fine silky schistose rocks, and seem to have been largely derived from basic lavas. They have suffered more than any of the other rocks from mechanical deformation, for they pass

* In the preparation of this Address I have had a large collection of thin slices cut from the more important rocks which I have myself collected, and to which I have occasion to refer in these pages. My colleague, Dr. Hatch, has been good enough to make a preliminary examination of this collection for me, and has supplied me with the notes from which the statements in the Address regarding the microscopic structure of the rocks are mainly taken.

into green chloritic schists. Some portions of them are not unlike the slaty tuffs of Llyn Padarn in Caernarvonshire.

Accompanying the fragmental volcanic rocks some ordinary sedimentary intercalations are to be found—red shales and pebbly quartzites that seem to have escaped much crushing.

Lastly, along the volcanic zone rise numerous craggy hills which mark the positions of bands and bosses, probably intrusive like the sills and bosses already noticed; they consist of gabbros which have been altered into epidiorite.

We thus learn that the local base of the Dalradian schists in the north of Ireland (probably not so low as the lower part of the series in central Scotland) consists of a volcanic group wherein the lavas, chiefly basic, show as distinct an amygdaloidal structure as can be found in any younger rocks, while the fragmental materials include coarse agglomerates and fine tuffs abounding in fragments of acid as well as basic lavas. It is worthy of notice that in this early volcanic group the two great classes of acid and basic rocks occurred in the ejections from the same centre of eruption, and that these ancient representatives of the two types resemble in essential features those of later periods. The singular freshness of so many of these rocks, and their escape in large measure from the shearing which produced the schists, suggest at first that they cannot possibly be part of the schistose series. But they are banded with true schist, and have thus partially suffered deformation, while the microscope reveals the large amount of internal change which they have undergone. That they have not been affected to a greater degree is possibly due to the protection afforded to them by the long Archæan ridge from the influence of the gigantic pressure which came from the south-east during the production of the foliation of the schists. Another instance of a similar kind lies on the north-west side of Ben Vuroch in Perthshire, where Mr. G. Barrow, of the Geological Survey, has found that under the lee of the granite of that mountain the limestone, which elsewhere has acquired the structure of a marble, still retains its original character, while its accompanying shales have not passed into schists. As is well known also, the cleavage which is so intense on the east side of the long quartz-porphyry ridge that crosses Llyn Padarn in Caernarvonshire almost disappears on its western side.

In the course of my investigation of the history of the earlier volcanic periods in British geology it has been necessary for me to

examine with some care the so-called "pre-Cambrian" rocks of Wales. So much has been written regarding these rocks, and so keen a contest has been waged over them, that a mere allusion to them, still more a decided statement of opinion regarding them, may possibly serve to revive the turmoil; for amid so wide a diversity of view one can hardly venture to express agreement with any one observer without seeming to place one's self in formal opposition to all the rest. I shall try to avoid anything approaching to the nature of controversy, and state as plainly as I can the results to which my own observations have led me. While it would be out of place here to offer even a brief summary of the voluminous literature which during the last twenty years has been devoted to the discussion of this subject, I shall take advantage of the opportunity which the present Address affords me to state where I think the work of the Geological Survey among these rocks has received important corrections from that of subsequent observers.

At the outset I wish to express my hearty admiration of the labours of my predecessors in the Survey of Wales. When we consider the condition of geology, and especially of petrography, at the time when these labours were carried on, when we remember the imperfection of much of the topography on the old one-inch maps (which were the only maps then available), when we call to mind the rugged and lofty nature of the ground where some of the most complicated geological structures are enclosed, we must admit that at the period when these maps and sections were produced they could not have been better done; nay, that as in some important respects they were distinctly in advance of their time, their publication marked an era in the progress of structural geology. The separation of lavas and tuffs over hundreds of square miles in a mountainous region, the discrimination of intrusive sheets and eruptive bosses, the determination of successive stratigraphical zones of volcanic activity among some of the oldest fossiliferous formations, were achievements which will ever place the names of Ramsay, Selwyn, Jukes, and their associates high in the bede-roll of British Geology. No one ever thinks now of making a geological excursion into Wales without carrying with him the sheets of the Geological-Survey map. These form his guide and handbook, and furnish him with the basis of information from which he starts in his own researches.

But science does not stand still. The most perfect geological map that can be made to-day will be capable of improvement thirty or

forty years hence. The maps of the Geological Survey are no exception to this rule. In criticizing and correcting them, however, let us judge them not by the standard of knowledge which we have now reached, but by that of the time when they were prepared. It is easy to criticize; it is not so easy to recognize how much we owe to the very work which we pronounce to be imperfect.

The ancient volcanoes of Wales, thanks mainly to the admirable labours of my old friend and former chief, Sir Andrew C. Ramsay, have taken a familiar place in geological literature. But a good deal has been learnt regarding them since he mapped and wrote. The volcanic history, as he viewed it, began in the Arenig period. The progress of subsequent enquiry, however, has shown that there are volcanic rocks older than the Llanberis Slates. I hope to be able to show in this Address that the Cambrian period in North Wales was eminently volcanic, and that there was probably a still earlier era of eruption.

I begin my narrative with Anglesey, which has been the subject of much discussion in reference to what has been called "the pre-Cambrian question." On the Geological-Survey map of that island * four areas are coloured as altered Cambrian (and partly Silurian) rocks, and an account of these areas is given in the Memoir on the Geology of North Wales †. The surveyors clearly recognized the metamorphosed character of the rocks in most parts of these four areas, and they saw that the crystalline schistose masses must be of far higher antiquity than the Arenig strata which they found to cover them unconformably, and to contain abundant fragments derived from their waste. Mr. Selwyn seems to have looked on the metamorphic rocks as of higher antiquity than any others in the region, and he wrote of them as "old green siliceous schists" and "old chloritic slates" ‡. Sir Andrew Ramsay, however, having formed certain hypothetical opinions regarding metamorphism, and having traced what he regarded as somewhat metamorphosed Cambrian strata from Caernarvonshire into Anglesey, came to the conclusion that the schists and gneisses of the latter district were only a further stage in the metamorphism of sedimentary rocks belonging mainly to some early part of the Cambrian system. Moreover, he recognized that dark shales containing Lower-Silurian

* Sheet 78 of the Geol. Survey Map.

† Memoirs of the Geol. Survey, vol. iii., 2nd edition, 1881.

‡ *Op. cit.* pp. 223, 227.

fossils were interstratified in the series of rocks forming the most northerly of his metamorphic areas in Anglesey, and he regarded the metamorphic rocks of that district as altered Llandeilo or Bala beds *. In the centre of the island he believed that a considerable extent of Silurian rocks had been metamorphosed into gneiss and mica-schist †.

These views have been impugned by Professors Hughes ‡ and Bonney §, Drs. Hicks || and Callaway ¶, the Rev. J. F. Blake **, and others. There is a general agreement among these writers that the rocks coloured on the Survey map are not altered Cambrian, but are of pre-Cambrian age. The most opposite opinions, however, have been expressed as to their nature and order. The latest view is that expounded by Mr. Blake, who has erected the so-called "pre-Cambrian" rocks of Anglesey into a new geological system to which he has given the name of "Monian."

Without attempting here to collate or criticize these diverse judgments, let me frankly say at once that in denying the existence of pre-Cambrian rocks in Anglesey, and in endeavouring to account for all the schists by the metamorphism of Cambrian and Silurian strata, my predecessor was, in my opinion, mistaken. I have little doubt that were he able once more to ramble over those hills and shores which he knew and loved so well he would himself, in the light of present knowledge, freely admit the error.

As no two observers agree in their reading of the pre-Cambrian rocks of Anglesey, I shall content myself with a brief statement of the main points as to which I believe the work of the Geological Survey requires amendment.

The rocks coloured on the map as altered Cambrian and Silurian embrace, I think, at least three totally distinct series. The whole of these have been claimed as pre-Cambrian. One of them, as I shall have occasion to show in a later portion of this Address, is certainly Lower Silurian, and was correctly so interpreted, in part at least, by

* *Op. cit.* pp. 224, 236, 240.

† *Op. cit.* p. 242.

‡ Quart. Journ. Geol. Soc. vols. xxxiv. (1878) p. 137, xxxv. (1879) p. 682, xxxvi. (1880) p. 237, xxxviii. (1882) p. 16; Brit. Assoc. Rep. 1881, pp. 643, 644; Proc. Camb. Phil. Soc. vol. iii. pp. 67, 89, 341.

§ Quart. Journ. Geol. Soc. vol. xxxv. (1879) pp. 300, 321; Geol. Mag. (1880) p. 125.

|| *Ibid.* vols. xxxiv. (1878) p. 147, xxxv. (1879) p. 295; Geol. Mag. (1879) pp. 433, 528.

¶ *Ibid.* vols. xxxvii. (1881) p. 210, xl. (1884) p. 567.

** *Ibid.* vol. xliv. (1888) p. 463.

Sir Andrew Ramsay. The other two are undoubtedly far older than at least any of the Cambrian rocks of Anglesey or Caernarvonshire, and one of them appears to me to be unquestionably Archæan. Their true stratigraphical relations may be partly made out from the writings of previous authors, each of whom has contributed his share to the progress of enquiry. But I was not prepared by a study of these writings for the interesting results which I have myself obtained, and which I now proceed to state.

In the first place, there is undoubtedly in central Anglesey a core of gneiss which, if petrographical characters may be taken as a guide, must certainly be looked upon as Archæan. In visiting that district recently with my colleague Mr. Teall I was much astonished to find there so striking a counterpart to portions of the old gneiss of the north-west of Sutherland and Ross. The very external features of the ground recall the peculiar hummocky surface which so persistently characterizes the areas of this rock from the far north of Scotland to the west of Ireland. If the geologist could be suddenly transported from the rounded rocky knolls of Sutherland or Galway to those in the middle of Anglesey south of Llanerchymedd, he would hardly be aware of the change save in the greater verdure of the hollows, which has resulted from a more advanced state of decomposition of the rocks at the surface as well as from a better agriculture.

When we come to examine these rocky hummocks in detail we find them to consist of coarse gneisses, the foliation of which has a prevalent dip to N.N.W. Some portions abound in dark hornblende and garnets, others are rich in brown mica, the folia being coarsely crystalline and rudely banded, as in the more massive gneisses of Sutherland. Abundant veins of coarse pegmatite may here and there be seen, with pinkish and white felspars and milky quartz. Occasionally the gneiss is traversed by bands of a dark greenish-grey rock, which remind one of the dykes of the north-west of Scotland. There are other rocks, some of them probably intrusive and of later date, to be seen in the same area; but they would require detailed study. My immediate object was attained when I had satisfied myself of the existence of a nucleus of rock which, so far at least as petrographical characters go, might with some confidence be regarded as Archæan.

In the second place, another and quite distinct series of schists occupies a large area in the west and in the centre and south of Anglesey. These rocks are obviously in the main a clastic series.

One of their most conspicuous members is quartzite, which, besides occurring sporadically all over the island, forms the prominent mass of Holyhead Mountain. There are likewise flaggy chloritic schists, green and purple phyllites or slates, and bands of grit, while parts of the so-called "grey gneiss" consist of pebbly sandstones that have acquired a crystalline structure. That some order of sequence among these various strata may yet be worked out is conceivable, but the task will be one of no ordinary difficulty, for the plications and fractures are numerous, and much of the surface of the ground is obscured by the spread of Palæozoic formations and superficial deposits.

These rocks are so obviously an altered sedimentary series that it is not surprising that they should have been regarded as metamorphosed Cambrian strata. All that can be positively affirmed regarding their age is that they are not only older than the lowest fossiliferous rocks of Anglesey—that is, than Arenig or even Tremadoc strata—but that they had already acquired their present metamorphic character before these strata were laid down unconformably upon them. There is no actual proof that they include no altered Cambrian rocks. But when we consider their distinctly crystalline structure, and the absence of any such structure from any portion of the Cambrian areas of the mainland; when, moreover, we reflect that the metamorphism which has affected them is of the regional type, and can hardly have been restricted to merely the limited area of Anglesey, we are led to realize that, in spite of the absence of positive proof of their true geological horizon, they must be of much higher antiquity than the Cambrian rocks of the neighbourhood. No one familiar with the Dalradian rocks of Scotland and Ireland can fail to be struck with the close resemblance which these younger Anglesey schists bear to them, down even into the minutest details. Petrographically they are precisely the counterparts of the quartzites and schists of Perthshire and Donegal, and a further connexion may be established of a palæontological kind. I can now announce that the upper part of the Holyhead quartzite was last autumn found by Mr. B. N. Peach and myself to be crowded with annelid-pipes, and that I subsequently found the same to be the case with the flaggy quartzites near the South Stack.

For my present purpose the feature of greatest interest about these younger schists of Anglesey is the association of igneous rocks with them. They include bands of dark basic material, the less crushed portions of which resemble the diabases of later forma-

tions, while the sheared portions pass into epidiorites and true hornblende-schists. Some of these bands are no doubt intrusive sills, but others may possibly be intercalated contemporaneous sheets. They occur across the whole breadth of the island from the Menai Strait to the shores of Holyhead. Besides these undoubtedly igneous rocks, the green chloritic slates deserve notice. They are well-bedded strata, consisting of alternations of foliated fine grit or sandstone, with layers more largely made up of schistose chlorite. The gritty bands sometimes contain pebbles of blue quartz, and evidently represent original layers of sandy sediment, but with an admixture of chloritic material. The manner in which this green chloritic constituent is diffused through the whole succession of strata, and likewise aggregated into bands with comparatively little quartzose sediment, reminds one of the "green schists" of the Central Highlands and Donegal, and suggests a similar explanation. Taken in connexion with the associated basic igneous rocks, these chloritic schists seem to me to represent a thick group of volcanic tuffs and interstratified sandy and clayey layers. If this inference is well founded, and if we are justified in grouping these Anglesey rocks with the Dalradian schists of Scotland and Ireland, a striking picture is presented to the mind of the wide extent and persistent activity of the volcanoes of that primeval period in Britain.

In the third place, to the north of a curving fault drawn upon the Survey map of the north of Anglesey from Carmel's Point on the west to Porth-y-Corwg on the east, a tract of country is coloured as altered Cambrian. In the Memoir on North Wales, however, Sir Andrew Ramsay expressed his doubts as to how far some of this area might not be Lower Silurian, for he showed that the strata included bands of black slate containing graptolites, and he was rather inclined to regard the whole series as Silurian *. This view has been rejected by Dr. Callaway and Mr. Blake, who regard most of the rocks north of the curved fault as pre-Cambrian †. On the other hand, Professor Hughes has expressed his belief in the general accuracy of Sir Andrew Ramsay's reference of the rocks to the Lower-Silurian series ‡.

I shall, however, have more to say respecting this part of Anglesey in a later section of my Address.

* *Op. cit.* pp. 224, 236, 242.

† Callaway, Quart. Journ. Geol. Soc. vol. xxxvii. (1881) p. 210; Blake, *op. cit.* vol. xl. (1884) p. 463.

‡ Proc. Phil. Soc. Cambridge, vol. iii. p. 347.

## III. URICONIAN.

Along the eastern borders of Wales a ridge of ancient rocks, much broken by faults and presenting several striking unconformabilities, has long been classic ground in geology from the descriptions and illustrations of the "Silurian System." The main outlines of the structure of that district, first admirably worked out by Murchison, were delineated on the maps and sections of the Geological Survey, wherein it was shown that in the Longmynd an enormously thick group of stratified rocks, which, though unfossiliferous, were referred to the Cambrian system, rose in the very heart of the country; that to the east of these rocks lay strata of Caradoc or Bala age; that by a great hiatus in the stratigraphy the Upper-Silurian series transgressively wrapped round everything below it; that yet again the Coal-measures crept over all these various Palæozoic formations, followed once more unconformably by Permian and Triassic deposits. Besides all this evidence of extraordinary and repeated terrestrial movement, it was found that the region was traversed by some of the most powerful dislocations in this country, while to complete the picture of disturbance many protrusions of igneous rocks were recognized.

In a territory so complicated, though it had been sedulously and skilfully explored, there could hardly fail to remain features of structure which had escaped the notice of the first observers. In particular, the igneous rocks had been dealt with only in a general way, and they consequently offered a favourable field for more detailed study; while, by a more searching examination of some of the rocks for fossils, important corrections of the earlier work might yet be made.

A notable step towards a revision of the received opinions regarding the igneous rocks of this region was taken by Mr. Allport, who showed that the so-called "greenstone" included masses of devitrified spherulitic pitchstones and perlites, together with indurated volcanic breccias, agglomerates, and ashes *. But the correction of the general view as to the geological age of these rocks is due to Dr. Callaway, who, after spending much time and labour in ascertaining by a careful search for fossils the position of the superincumbent rocks (wherein he discovered Cambrian organisms), and in a detailed investigation of the structure and relationships of the igneous masses themselves, was led to regard them as part of an

* Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 449.

ancient pre-Cambrian ridge; and he proposed for the volcanic group the name of Uriconian, from the name of the ancient Roman town which stood not far to the west of them *. Mr. Blake, in subsequently criticizing some of Dr. Callaway's conclusions, and in endeavouring to establish an unconformability in the middle of the Longmynd rocks, has contended that the volcanic rocks of the Wrekin district are of later date than the Longmynd slates, and he suggests that they may even be part of the Cambrian series of that neighbourhood †. Professor Lapworth, as is well known, at least to his friends, has devoted his leisure for some years past to the detailed investigation of the older rocks of Western England, and has mapped them with minute care upon the six-inch maps of the Ordnance Survey, some of which were exhibited at the International Geological Congress in 1888. He has not yet published more than brief allusions to some of his principal results, such, for instance, as the detailed sequence of the Arenig-Bala formations, his discovery of the *Olenellus*-fauna, marking the lowest known fossiliferous Cambrian zone in the Wrekin district, and his recognition of Cambrian fossils under the Coal-measures of Warwickshire ‡. When he learnt that I proposed to make a personal examination of a portion of the ground, he not only most generously offered me the use of his unpublished six-inch maps and furnished me with copious notes for my guidance, but he even accompanied me over some of the typical sections, and enabled me to see for myself certain critical parts of the evidence.

For my present purpose it will be sufficient for me to state very briefly the nature of the volcanic rocks which are claimed by Dr. Callaway as pre-Cambrian in the Shropshire area, and how far I think that the evidence of so high antiquity for them is trustworthy.

These igneous masses form the core of the ancient ridge which extends from near Wellington through the Wrekin, Caer Caradoc, and other hills until it sinks beneath the Upper-Silurian formations. They consist partly of lavas, partly of volcanic breccias and fine tuffs. The lavas are thoroughly acid rocks of the felsitic or rhyolitic type. One of them, about 100 feet thick, which forms a pro-

* *Op. cit.* vols. xxx. (1874) p. 196, xxxiv. (1878) p. 754, xxxv. (1879) p. 643, xlii. (1886) p. 481.

† *Op. cit.* vol. xlvi. (1890) p. 386. Dr. Callaway has replied to these objections in a paper not yet published.

‡ Geol. Mag. (1882) p. 563; (1886) p. 319; (1887) p. 78; (1888) p. 484.

minent feature on the flanks and crest of Caer Caradoc, shows abundant finely banded flow-structure, often curved or on end, while its bottom and upper parts are strongly amygdaloidal, the cavities being occasionally pulled out in the direction of flow and lined with quartz or chalcedony. Some of the detached areas of eruptive rocks show the beautiful spherulitic and perlitic structures first noticed in this region by Mr. Allport.

The breccias and tuffs appear to consist mainly of felsitic material. In the coarser varieties fragments of finely banded felsite may be noticed, while the finer kinds pass into a kind of hornstone (hälleflinta), which in hand-specimens could hardly be distinguished from close-grained felsite. In some places these pyroclastic rocks are well stratified, but elsewhere no satisfactory bedding can be recognized in them. Various other rocks which are probably intrusive occur in the ridge. At either end of the Wrekin there is a mass of pink microgranite, while at Caer Caradoc numerous sheets of "greenstone," intercalated in the fine tuffs, sweep across the hill. That some at least of these basic rocks are intrusive is manifest by the way in which they ramify through the surrounding strata. But others are so strongly amygdaloidal and slaggy that they may possibly be true interbedded lavas, though it is difficult to understand how such basic outflows could be erupted in the midst of thoroughly acid ejections. Leaving these doubtful flows out of account, we have here a group of undoubted volcanic rocks represented by acid lavas and pyroclastic materials, by intrusive bosses of acid rocks, and by younger basic sills. The general lithological characters of these masses and the sequence of their appearance thus strongly resemble those of subsequent Palæozoic volcanic episodes.

The geological age of this volcanic group is a question of much interest and importance in regard to the history of vulcanism in this country. An inferior limit to its antiquity can at once be fixed by the fact that, as originally pointed out by Dr. Callaway, the quartzite which overlies the volcanic rocks passes under a limestone containing Cambrian fossils in which Professor Lapworth has since recognized *Olenellus*, *Paradoxides*, and other Lower-Cambrian forms. The eruptions, therefore, must be at least as old as the earlier part of the Cambrian period. But it is affirmed that the quartzite rests with a complete unconformability on the volcanic rocks. If this be so, then the epoch of eruption must be shifted much farther back.

The evidence adduced in favour of this great break appears to me

to be threefold. In the first place, the quartzite contains fragments of the volcanic rocks. I do not think much stress can be laid on this fact. What struck me most in the composition of the quartzite was its singularly pure quartzose character, and the comparative scarcity of felsite-pebbles in it. Any deposit laid down conformably upon the top of the breccias and tuffs might obviously contain some of these materials, while, if laid down unconformably, it might reasonably be expected to be full of them. In the second place, this quartzite is alleged to pass transgressively across the edges of successive sheets of the volcanic group, and thus to have a quite discordant dip and strike. I failed to find satisfactory evidence of this unconformability in the northern part of the district. But in the Caer-Caradoc area the quartzite does appear to steal across the outcrops of the older rocks which plunge at nearly right angles in an opposite direction. In the third place, the felsitic volcanic group is believed by Professor Lapworth to pass upwards into the Longmynd rocks. Obviously, if this group lies at the very bottom of the vast Longmynd series, the discordance between it and the quartzite must be enormous, and the date of the volcanic eruptions must be placed vastly farther back in geological antiquity. Though the evidence does not seem to me to amount to clear proof, I am disposed, in the meantime, to accept it as affording the most probable solution of the difficulties presented by the structure of the ground.

If, then, the volcanic group underlies the whole of the Longmynd series, and if, as it now appears, that series is older than the *Olenellus*-zone of the Lower-Cambrian rocks, we can hardly include the volcanic rocks of the Wrekin and Caer Caradoc in the Cambrian system. They must belong to a still older geological formation, and I think we cannot do better than adopt for them Dr. Callaway's name, Uriconian.

There are still, however, many problems to be solved before the geological history of that region is fully understood. The rocks of the Longmynd must be more fully worked out. It is incredible that strata which look so likely to yield fossils should for ever prove barren. The lower half at least may be hopefully searched, although the upper massive reddish sandstones and conglomerates offer less prospect of success. On the west side of the Longmynd above Pontesbury there occurs a small area of volcanic rocks like those of the Wrekin district, including a well-marked nodular felsite and fine tuffs. These rocks have been regarded by Dr. Callaway

as another axis of the Uriconian series. It is very difficult, however, by any combination of geological structures to bring up a portion of the very bottom of the Longmynd series and place it apparently at the top. This is a feat which a detailed study of the region and the detection of unconformabilities in the Longmynd may possibly accomplish. In the meantime, however, I would venture to suggest whether it is not more probable that we have here a detached area of much younger volcanic rocks, like those which, in various districts, may be included in the Cambrian system.

## IV. CAMBRIAN.

Under this name I class all the known Palæozoic rocks which lie on each other conformably below the bottom of the Arenig group. It was maintained by Sir Andrew Ramsay and his colleagues on the Geological Survey that on the mainland of Wales no base is ever found to the Cambrian system. More recently certain conglomerates have been fixed upon as the true Cambrian base, both in South and North Wales, and endeavours have been made to trace an unconformability at that line, all rocks below it being treated as pre-Cambrian. I have formerly insisted that conglomerates do not necessarily mark a stratigraphical discordance, and that in South Wales there is no trace of any unconformability between the strata above and below the supposed line of break *. Professor Bonney has shown that in North Wales several zones of conglomerate have been erroneously identified as the supposed basal platform of the Cambrian series, and more recently Mr. Blake has pointed out that some of these conglomerates are unquestionably Lower Silurian. My own examination so far confirms the conclusions arrived at by these observers. Like my predecessors in the Survey, however, I have been unable to detect anywhere in Caernarvonshire or Merionethshire a base to the Cambrian system, and I am compelled to agree with them in regarding as Cambrian (partly even as Lower Silurian) all the rocks from Bangor to Llanllyfni, which have more recently been classed as pre-Cambrian. But though thus supporting their general stratigraphy, I am bound to acknowledge that they failed to recognize the existence of a great volcanic series below the Arenig horizon. The existence of this series, noticed by Sedgwick, was first definitely stated by Professor Hughes †, and his

* Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 305.

† Proc. Camb. Phil. Soc. vol. iii. (1877) p. 89.

statements have been confirmed and extended by subsequent observers, notably by Professor Bonney and Mr. Blake *. But I venture to think that its real position and range have hitherto escaped notice, and that it proves the Cambrian to have been a period perhaps even more continuously volcanic than the Lower Silurian was in Wales.

In the vast pile of sedimentary material of the Harlech anticline, estimated by the Geological Survey to be from 6000 to 7000 feet thick, no trace of any contemporaneous volcanic rocks has been met with †. Dr. Hicks, indeed, has referred to certain "highly felsitic rocks, for the most part a metamorphic series of schists, alternating with harder felsitic bands, probably originally felsitic ashes," lying at the bottom of the whole pile, and he has claimed them as pre-Cambrian ‡. But I could not find any evidence of such rocks, nor any trace of igneous materials save dykes and sills, acid and basic, such as are indicated on the Survey map. The purple slates that rise along the centre of the anticline dip below the grits and conglomerates on either side without allowing us a glimpse of the base of the system. This enormous accumulation of sedimentary deposits seems to diminish in thickness as it is traced northwards, for towards the Menai Strait it does not reach more than a fourth part of the depth which it displays in the Harlech anticline §. In the Pass of Llanberis the series of grits that overlies the purple slates is estimated to be about 1300 feet thick ‖. This gradual thinning away of the Cambrian series towards the north was, in the opinion of Sir Andrew Ramsay, accompanied by an increasing metamorphism of the lower portions of the system. In his view, the long ridge of quartz-porphyry which crosses the lower end of Llyn Padarn represents the result of the extreme alteration of the stratified rocks. He believed that he could trace an insensible passage from the slates, grits, and conglomerates into the porphyry, and he was led to the "conviction that the solid porphyry itself is nothing but the result of the alteration of the stratified masses carried a stage further than the stage of porcellanite, into the condition of that kind of absolute fusion that in many other regions seems to have resulted in the formation of granites, syenites, and other rocks, commonly called intrusive" ¶. Certain structural

* In the papers already quoted on p. 82.

† Mem. Geol. Surv. vol. iii. 2nd edit. Geology of North Wales, p. 21.

‡ Geol. Mag. (1880) p. 519.

§ Mem. Geol. Surv. vol. iii. 2nd edit. p. 24. ‖ *Op. cit.* p. 173.

¶ *Op. cit.* p. 173.

lines in the quartz-porphyry he looked upon as indicating "traces of stratification in a rock, the original felspathic and quartzose material of which has been metamorphosed into true porphyry"*. In conformity with these ideas, the remarkable felspathic strata which lie nearest the porphyry were regarded as metamorphosed Cambrian rocks, and where similar rocks reappear over a large area near Bangor they were coloured on the map with the same tint and lettering as were used for the so-called "altered Cambrian" of Anglesey.

No one who has examined this Caernarvonshire ground can have failed to find the sections which doubtless led my predecessor to form the convictions to which he gave expression in the passages I have just quoted. It is easy to see how these sections, wherein it is certainly difficult to draw a sharp line between the igneous rock and the clastic materials derived from it, would be welcomed as appearing to offer confirmation of the ideas concerning metamorphism which were then in vogue. There cannot, however, be any doubt that my friend was mistaken in his interpretation of the structure of that part of the country. It is to me a subject of keen regret that he should be now no longer able to re-examine this ground himself, for no one would have confessed more frankly his error, and done more ample justice to those who, coming after him, have been able in some parts to correct his work.

The quartz-porphyry, felsite, or rhyolite of Llyn Padarn, as well as that of Llandeiniolen, is not a metamorphic but an eruptive rock, as has been demonstrated by Professors Hughes and Bonney. There is no true passage of the sedimentary rocks into it; on the contrary, the conglomerates which abut against it are in great part made out of its fragments, so that it must have been already in existence before these Cambrian strata were deposited. These conclusions must be regarded as wholly indisputable. But most of the critics of the work of the Survey have proceeded to certain further deductions. They have maintained that the presence of fragments of the porphyry in the overlying conglomerate marks an unconformability between the two rocks, that the conglomerate shows the base of the Cambrian system, and that the porphyry is therefore pre-Cambrian. These assertions and inferences do not seem to me to be warranted. They have already, in my judgment, been disproved by Mr. Blake in an excellent memoir read before the Society in 1888, with the main conclusions of which I agree. Mr. Blake shows, in my opinion conclusively, that there is no break in the Cambrian

* *Ibid.* p. 174.

series, that the various porphyries and their accompaniments are parts of that series, and that there is no certain proof of the existence of any pre-Cambrian rocks in the whole district *.

That the igneous rocks of the Llyn-Padarn area mark a volcanic period has been recognized by most writers, since Professor Bonney pointed out the flow-structure of the quartz-porphyry, and other proofs of active volcanic eruptions have been traced by him as well as by Professor Hughes and Mr. Blake in the stratified rocks which stretch north-eastwards to Bangor. But the extent and persistence of these ancient volcanic phenomena, and their probable connexion with the remarkable northward attenuation of the Cambrian sedimentary rocks, have hardly received adequate attention.

It is generally agreed that the rocks variously termed quartz-porphyries, felsites, or rhyolites, form the oldest members of this volcanic series †. They come to the surface in two long ridges, one running from Caernarvon to near Bangor, the other from Llanllyfni to Ann's Chapel, at the mouth of Nant Francon. Whether the materials of these two ridges are parts of one originally continuous sheet or group of sheets, or, if different protrusions, whether they belong to the same geological horizon, or whether, as Mr. Blake believes, they are distinct masses, separated by a considerable thickness of detrital material, cannot in the present state of our knowledge be positively decided. It seems to me probable that they are connected underground, as a continuous platform beneath the overlying pyroclastic materials. They have been regarded as intrusive sheets, more recently as lava-streams that were poured out at the surface. If we take account simply of their petrographical characters, we must admit that they find their nearest analogies among the intrusive quartz-porphyries of older geological periods. The presence of flow-structure in them has been thought to indicate that they were superficial streams. But this structure may be found in dykes and intrusive sheets as perfectly as in lava-flows, so that it cannot by itself be taken as proof of a surface-discharge of lava. It must be confessed that, both in the main mass of quartz-porphyry and in the abundant fragments of it in the overlying conglomerates and breccias, there is an absence of such scoriform portions as one would naturally look for in a superficial lava-stream; while, on the other hand, the rock generally presents the tolerably uniform flinty texture so familiar

* Quart. Journ. Geol. Soc. vol. xliv. p. 271.

† Whether the granitic rock of Twt Hill, Caernarvon, is connected with the porphyry or belongs to an older eruption is immaterial for my present purpose.

in intrusive sheets of similar material. Mr. Blake, indeed, has brought forward the evidence of a section on the north or under side of the Llyn-Padarn ridge, to show that the rock has there been intruded into the Cambrian strata *. My own impression is that these igneous masses were probably erupted to the surface as long banks which rose above the waves ; that they were thus exposed to prolonged subaerial and marine denudation ; that by this means the upper more cellular portions of the lava were broken up and pounded down into detritus, and thus that what is now visible is a part of the eruptive rock which originally lay at some depth within its body. This view is confirmed by a study of other lavas which are found on different platforms in the detrital deposits that overlie the Llyn-Padarn quartz-porphyry.

That the material of each of the two main ridges is the result of more than one eruption has been inferred from the intercalation of bands of slate and of breccia in the rock †. Considerable lithological differences may be detected in each mass, but they are not greater than may be observed in single sheets. In some parts of the Llyn-Padarn porphyry a distinct nodular structure appears which shades off into bands and lenticular streaks, reminding one of the characters of some of the Bala rhyolites. Other portions are markedly brecciated, the separated fragments being surrounded in a matrix of the rock, which shows flow-structure sweeping past them. On Moel Gronw angular fragments of a dark pinkish tint are scattered through the general mass. Again, some parts are crowded with quartz-grains, while others are comparatively free of these, and occasionally a spherulitic structure has been observed ‡.

The microscopic structure of this ancient eruptive rock has been studied by Professor Bonney, who found that the general type was a compact dull grey felsite with porphyritic crystals of felspar and grains of quartz, closely resembling some modern rhyolites. Though unable to detect any actual glass in the base, he had no doubt that the rock was originally vitreous, and he found abundant and fresh examples of the most perfect flow-structure §.

Reference may be made here to the remarkable influence of the intense cleavage of the district upon this rock ||. Along its southern

* Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 283.

† See for example, Bonney, Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 312; Blake, *op. cit.* vol. xliv. (1888) pp. 277, 287.

‡ Blake, *ibid.* p. 277. § *Op. cit.* vol. xxxv. p. 312.

|| The secondary planes due to cleavage must not be confounded with the original flow-structure.

margin, where it has been exposed to the pressure from the south-east, the quartz-porphyry has been so crushed that it passes here and there into a fine unctuous slate or almost a schist. Nowhere can this change be more clearly seen than on the slopes of Mynydd y Cilgwyn. The cleavage-planes strike about N. 40° E., with an inclination to dip towards the N.W. Within a space of a few yards a series of specimens may be collected showing at one end an ordinary or only slightly sheared quartz-porphyry with abundant quartz-blebs, and at the other a fine greenish sericitic slate or phyllite, wherein the quartz has been almost entirely crushed down. Lines of shearing may be detected across the breadth of the porphyry ridge, each of them coinciding with the prevalent trend of the cleavage. Sometimes also the basic dykes, which traverse the porphyry in some numbers, have undergone considerable deformation from the same cause. Their thinner portions are so well cleaved that at the first glance they might quite easily be mistaken for included bands of green slate. But these cleaved branches may sometimes be traced into a thicker and more solid dyke, whose uncrushed cores still preserve the original character of the rock and prove it to be eruptive.

The rocks which succeed the porphyry in the Valley of Llanberis are of great interest, for they contain abundant proof of contemporaneous volcanic activity, and they show that, so far from there being any marked hiatus here, there is evidence of the persistence of eruptions even in the time of the Llanberis Slates. Considerable misapprehension has arisen from the attempt to make the conglomerate the base of the Cambrian series, and the real significance of the volcanic detrital strata in association with it has been missed. The conglomerate does not lie on one definite horizon. In truth there are several zones of conglomerate, each with some difference of composition, thickness, or extent *. These may be well studied both on the south and the north side of the porphyry ridge at the lower end of Llyn Padarn. They are intercalated among fine tuffs, ashy grits, volcanic breccias, and purple slates, sometimes full of fine ashy material. On the south-east side of the ridge, where the rocks have suffered intense cleavage, they assume a fissile unctuous character, and then resemble parts of the cleaved tuffs in the

* I could find no evidence of unconformability beneath the conglomerate. The section described by Professor Green, Quart. Journ. Geol. Soc. vol. xli. (1885) p. 74, is explicable, I think, by the difference between the effects of cleavage on the fine tuffs and the more massive resisting conglomerate which overlies them.

Cambrian series at St. David's. But on the north-west side, where they have in large measure escaped the effects of the cleavage-movements, their original structures are well preserved.

One of the first features of these detrital deposits to arrest attention is the amount and variety of the fragments of igneous rocks in them. Some of the conglomerates, though enclosing pebbles of quartz, quartzite, granite, and other rocks not found *in situ* in the immediate district, are mainly composed of the débris of the quartz-porphyry of the ridge. Indeed, this latter material appears to have contributed a large proportion of the detritus of which the general body of strata here is made up. But there are to be noticed among the contents of the conglomerates and breccias pieces of many volcanic rocks not to be found on the porphyry ridge. Among these, besides felsites showing sometimes beautiful flow-structure (rhyolites) and various quartz-porphyries, there occur abundant fragments of less acid lavas (andesites) and pieces of older tuffs. Some of the fragmental rocks are green in colour, probably from the abundance of fine basic volcanic dust in them. Certain bands are full of large angular pieces of shale similar in character to the Cambrian slates, and doubtless due to the disruption of pre-existing Cambrian strata by volcanic explosions. It is clear that from vents in this neighbourhood there continued to be an abundant discharge of dust and various andesitic and other lapilli, which, falling on the sea-floor, mingled there with the ordinary mechanical sediment that was being deposited at the time.

But we have evidence that during the period when these showers of volcanic detritus were thrown out streams of lava, though on a greatly diminished scale, continued to be poured forth. The hill of Clegyr, near the lower end of Llyn Padarn, consists mainly of cleaved tuffs, slates, and conglomerates overlying the quartz-porphyry. Near the summit a band of felsite is intercalated in these rocks. But still more striking are the sections on the south side of the lake. Starting from the porphyry of the ridge we cross a zone of conglomerate and grit largely composed of the débris of the porphyry, until we reach a band of felsite or quartz-porphyry, which at its eastern end is about ten feet thick, while it seems to increase in dimensions westwards. In the centre the rock is dark purplish-red, exceedingly compact or flinty, sprinkled with a variable proportion of quartz-blebs and felspar crystals. Towards its southern or upper edge (for the rocks, though nearly vertical, dip southwards) it has been cleaved into a variety of purple slate, and

would there at once be classed among the ordinary slates of the neighbourhood. But the fissile character is merely a marginal structure which the rock shares with the highly cleaved tuffs that follow it. Traced westwards, this bed is found to enclose a quartziferous core, which is also cleaved along the margin as well as partially in the interior. It would not be possible to distinguish parts of this intercalated band from portions of the porphyry of the main ridge. The difference of colour does not count for much, for even in this band the purple tint gives place to greenish grey, and what in the centre at the east end is a solid dark purplish-red felsite passes westward into a greenish slate, like that already noticed on Mynydd y Cilgwyn.

The microscopical examination of this rock shows it to be a true felsite of the rhyolitic type, which in the central uncleaved part exhibits a wavy flow-structure like that found in the quartz-porphyry of the ridge. So intense has been the cleavage in its upper part that the original structure of the rock is there effaced. The immediately overlying tuffs, which are likewise so thoroughly cleaved that it is not easy to draw a sharp and continuous line between them and the intercalated lava, precisely resemble those found below the conglomerate on the opposite side of the lake. They include bands of coarse volcanic breccia as well as fine compact material, showing the varying intensity of the volcanic discharges. Their included stones consist of various felsites, andesites, and slates.

The thin sheet of interstratified quartz-porphyry here described is not the only one to be found in the section. Others thinner and more intensely cleaved lie among the tuffs higher up. They have been sheared into mere pale unctuous slates, but the remains of their quartz-blebs may still be detected in them.

The tuffs, with their interstratified bands of porphyry, become more and more mingled with ordinary argillaceous and sandy sediment as they are followed in upward succession. Among them occur bands of grit and fine conglomerate containing pebbles of porphyry and pieces of slate. Some of these grits are mainly composed of white felspar, felsite, and clear grains of quartz, evidently derived from the disintegration of a rock like the porphyry of the main ridge. As the ordinary sediment of the Llanberis group sets in, the tuffs are restricted to thinner and more widely separated bands. Some thin layers of felspathic breccia, seen among the slates close to the Glyn Peris Hotel, probably mark the last discharges of the

slowly expiring vents of this region. No more striking evidence could be desired of a gradual extinction of volcanic action. Through many hundreds of feet of strata which now supervene, representing the closing ages of the Cambrian and the earlier ages of the Silurian period, no trace of volcanic material has been found in this district until we reach the Bala lavas and agglomerates of Snowdon and the Pass of Llanberis.

In the neighbourhood of Bangor another area of similar rocks wraps round the northern end of the western porphyry ridge. The Geological-Survey map, in conformity with the ideas that governed its representation of the older rocks of Anglesey and Caernarvon, colours these as altered Cambrian. That this error should have been made, or, when made, should not have been speedily corrected, is all the more surprising when we consider the thorough mastery which the surveyors had acquired of the aspects and the interpretation of ancient volcanic rocks in Wales, and when, moreover, we remember that as far back as 1843, long before the Survey of Caernarvonshire was published, Sedgwick had pointed out the true volcanic nature of the rocks. That great pioneer recognized the presence of "trappean conglomerates" and "trappean shales (Schaalstein)" among these deposits at Bangor; but he could not separate them from the Cambrian series of the rest of Wales *. And in his section he represents them as undulating towards the east and passing under the great mass of the Caernarvon slates and porphyries.

This interpretation, which I believe to be essentially accurate, was modified by Professor Hughes, who, fixing on a conglomerate as the base of the Cambrian system, regarded all the rocks below it, or what he termed his "Bangor group," as pre-Cambrian †. He has been followed in this view by subsequent writers ‡; but Mr. Blake has more recently argued that here, as in the Llanberis district, there is no evidence to separate the volcanic detrital deposits above the porphyry from the Cambrian system §.

A little southward from Bangor the quartz-porphyry is overlain by a most interesting group of fragmental rocks, the "Bangor group" of Professor Hughes. These are largely of volcanic origin; they must be some hundreds of feet thick, and pass under the

* See Proc. Geol. Soc. vol. iv. p. 212; Quart. Journ. Geol. Soc. vol. iii. (1847) p. 136.

† Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 137.

‡ Bonney, *op. cit.* vol. xxxv. (1879) p. 316; Hicks, *ibid.* p. 296.

§ *Op. cit.* vol. xliv. (1888) p. 278.

dark shales and grits of the Lower-Silurian (Arenig) series. Some of the most persistent bands among them are conglomerates, which differ from each other in composition, but most of which consist largely of fragments of various igneous rocks. Some of the coarser masses might be termed agglomerates, for they show little or no trace of bedding, and are essentially made up of blocks of volcanic material. There are abundant beds of grit, sometimes pebbly or finely conglomeratic, alternating with tuffs and with bands of more ordinary sediment. Courses of purple shale and sandstone, green shale, and dark grey sandy shale occasionally occur to mark pauses in the volcanic explosions. Perhaps the most striking feature in the pyroclastic materials is the great abundance of very fine compact pale tuffs (hälleflintas of some writers), sometimes thinly laminated, sometimes occurring in ribbon-like bands, each of which presents internally a close-grained, almost felsitic or flinty texture.

A cursory examination of the contents of the conglomerates, breccias, and grits shows them to consist largely of different felsites, with fragments of more basic lavas. Some of these might obviously have been derived from the rock of the porphyry ridge, but, as at Llyn Padarn, there is a far greater variety of material than can be found in that ridge. Some of the fragments show perfect flow-structure. Professor Bonney has described the microscopic characters of some of these fragments, and has especially remarked upon their glassy character. Among the slides prepared from specimens collected by myself, besides the abundant fragments of felsite (rhyolite) there are also numerous pieces of different andesitic lavas and fine tuffs, as well as grains of quartz and felspar, and sometimes a good deal of granular iron-ore.

That a large proportion of the material of the so-called "Bangor beds" was directly derived from volcanic explosions can hardly be doubted. There appears to have been a prolonged succession of eruptions, varying in intensity, and somewhat also in the nature as well as in the relative fineness of the material discharged. On the one hand, there are coarse massive agglomerates which were probably accumulated not far from the active vents as the result of more violent explosions; on the other hand, exceedingly fine and well-stratified tuffs which attain a great thickness and serve to indicate the persistence of a phase of eruptivity marked by the discharge of fine volcanic dust. Ordinary sediment was doubtless drifted over the sea-bottom in this district during the

volcanic episode, but the comparative infrequence of distinct interstratifications of shale or sandstone may be taken to imply that as a rule the pauses between the eruptions were not long enough to allow any considerable accumulation of sand or mud to take place.

No satisfactory proof has yet been obtained of any interstratified lavas among the tuffs of the Bangor district. Some rocks, indeed, can be seen on the road between the George Hotel and Hendrewen which, if there were better exposures, might possibly furnish the required proof; but at present little can be made of them, for their relations to the surrounding rocks are everywhere concealed.

From what I have now adduced, it is obvious that while both felsitic and andesitic lavas existed within the volcanic foci, and were ejected in fragments to form the tuffs and breccias, the lavas poured out at the surface during the Cambrian period in Caernarvonshire were mainly, if not entirely, felsites (rhyolites) in which the chief porphyritic constituent was quartz. These lavas thus stand entirely by themselves in the volcanic history of Wales. Though felsites of various types were afterwards poured out, nothing of the same quartziferous kind, so far as we yet know, ever again appeared.

I have now to consider the relation of this volcanic group of Bangor to the strata which overlie it. The geological horizon of these strata is not, perhaps, very definitely fixed. It may be Arenig, possibly even older. But for my present purpose it will be sufficient to consider the strata in question as lying at the bottom of the Lower-Silurian series. Professors Hughes and Bonney have taken as their base a marked but impersistent band of conglomerate. Mr. Blake, however, has more recently shown that, as this band is succeeded by tuffs like those below it, it cannot be claimed as marking the upper limit of the volcanic group. He therefore classes it in that group and traces what he thinks is an overlap or unconformability at the bottom of the Lower-Silurian strata to the east. Mr. B. N. Peach, who accompanied me in an examination of this ground, agrees with me in confirming Mr. Blake's observation as to the position of the conglomerate, which is undoubtedly overlain by the same flinty felsitic tuffs as are found below it. But we were unable to trace any unconformability. According to the numerous observations which we made, there does not seem to be any discordance in strike or dip between the flinty tuffs and the overlying shales and grits. The two groups of rock appeared to us to be conformable and to pass into each other as at Llyn Padarn.

An unconformable junction here would, in some respects, have

been welcome, for it would at once have accounted for the superposition of Lower-Silurian strata directly upon the Cambrian volcanic series and for the disappearance of the Llanberis slates and grits which form so conspicuous a feature above the tuffs and conglomerates at Llyn Padarn. In the absence of such a structure we must accept the order of succession as apparently unbroken and rely on some such explanation as was proposed by Sir Andrew Ramsay to account for the overlap of the Arenig rocks on everything older than themselves as they are traced northwards *. But this explanation will not entirely remove the difficulties of the case. The inosculation of the volcanic group of Bangor with the base of the Lower-Silurian series cannot be accounted for by any such overlap; it seems only explicable on the supposition that the volcanic activity which ceased in the Llyn-Padarn district about the time that the Llanberis Slates were deposited was continued in the Bangor area until Arenig time, or was then renewed. The thick volcanic group of Bangor would thus be the stratigraphical equivalent not only of the thin volcanic group of Llyn Padarn, but of the overlying mass of strata up to the Arenig rocks. In confirmation of this view I shall subsequently attempt to show that volcanic action was prolonged in Anglesey to a still later geological period, that it appeared during the deposition of the Arenig strata, and that it attained a great development throughout the time of the Bala group.

During the last ten years, thanks mainly to the labours of Dr. Callaway and Professor Lapworth, much new light has been cast upon the occurrence of Cambrian rocks in the west and centre of England. We now know that portions of the Cambrian system protrude in the very heart of the country, and that below these strata a distinct volcanic group may be recognized. The tract where the relations of this group to the overlying Cambrian strata are best seen is along the north-east slopes of the long ridge which comes out from under the Warwickshire coal-field between Atherstone and Nuneaton. Grey, black, purple, and green shales containing a characteristic Upper-Cambrian fauna rest upon a mass of bedded quartzite which may be about 1200 feet thick. Beneath this quartzite, and presenting the same general strike and amount of metamorphism, comes a marked volcanic group consisting of well-stratified ashes, with felsite which may possibly be intrusive in them, and a diabase-porphyrite which traverses the felsite. The base of

* Mem. Geol. Surv. vol. iii. 2nd edit. p. 252.

the quartzite contains fragments of the volcanic rocks, but, as I have already pointed out, such a fact is of little value in establishing an important break between a group of volcanic and one of ordinary sedimentary rocks *. According to present evidence, the volcanic group may most naturally be regarded as a part of the Cambrian series.

Not many miles to the north-east, in the Charnwood-Forest district, numerous isolated protrusions of ancient rocks rising from among the red sandstones and marls of the great Midland Plain have long given rise to speculation among geologists. They were regarded as of Cambrian age by the Geological Survey, and they have since been carefully studied by Professor Bonney and the Rev. Edwin Hill †. I allude to them here because they include a group of undoubtedly volcanic materials such as ashes and agglomerates. Their true geological relations can hardly be demonstrated, for they are surrounded by much younger rocks, but there seems some probability that they belong to the same series as that of Nuneaton, and that they may thus bear additional testimony to the volcanic activity which marked the Cambrian period in this country.

One other volcanic area requires notice here—that of St. David's, in South Wales. Though, for the sake of geographical continuity, I have deferred its consideration until after the description of the corresponding tracts in North Wales and the west and centre of England, it was the first district where volcanic rocks of contemporaneous origin were shown to underlie strata of Cambrian date. It has received a large amount of attention from geologists, mainly owing to the labours of Dr. Hicks, who was led to recognize the true volcanic character of the deposits below the fossiliferous Cambrian rocks. He named them Pebidian, regarding them as pre-Cambrian and as separated by an unconformability from the base of the Cambrian system. Much discussion has arisen over his interpretation of the structure of the district ‡. Having already entered the lists with him, I shall avoid here any renewal of the controversy, confining myself to mere reiteration of views which I have

* Lapworth, Geol. Mag. (1886) p. 319; T. H. Waller, *loc. cit.*; A. Strahan, *op. cit.* p. 540.

† Quart. Journ. Geol. Soc. vols. xxxiii. (1877) p. 754, xxxiv. (1878) p. 199, xxxvi. (1880) p. 337.

‡ See especially Hicks, Quart. Journ. Geol. Soc. vols. xxxi., xxxiii., xxxiv., xl.; Geikie, *op. cit.* vol. xxxix. (1883); Blake, *op. cit.* vol. xl. (1884); Lloyd Morgan, *op. cit.* vol. xlvi. (1890).

already expressed, and from which I have as yet seen no reason to depart.

Below the lowest fossiliferous Cambrian strata at St. David's there lies a volcanic group consisting of tuffs and breccias, with contemporaneously erupted and subsequently intruded massive rocks. About 1800 feet of these various materials are visible, but the bottom of the group is nowhere reached. The tuffs belong to two groups—one derived from the explosion of diabase-lavas and containing about 50 per cent. of silica, the other arising from the discharge of felsitic fragments and consequently showing as much as 70 to 80 per cent. of silica. The basic and acid detritus are mingled in some bands, producing materials of intermediate composition. The texture of the tuffs varies from fine silky schists to somewhat coarse breccias or agglomerates. Most of these fragmental rocks are basic in character, the more acid varieties occurring as occasional interstratifications, but rather predominating in the upper parts. Thus, while the eruptions usually discharged diabase detritus, there would seem to have been occasional explosions from felsitic lavas, and apparently a prevalence of the latter towards the close of the volcanic period.

The interbedded lavas, unlike those of Caernarvonshire, include olivine-diabases, sometimes strongly amygdaloidal or presenting slaggy characters. These are dull, fine-grained, sparingly porphyritic rocks, and range in colour from epidote-green to dull blackish green and dark chocolate-brown. They contain less than 46 per cent. of silica and about 10 per cent. of magnesia. Their abundant augite is minutely granular, and their olivine is in great part replaced by hæmatite. There occur also sheets of porphyrite among the tuffs. These lavas form but a small proportion of the whole volcanic group. An intrusive boss of granite rises among the rocks, and around it are quartz-porphyries (granophyres), probably its apophyses, which traverse the volcanic group, while later still come intrusive sheets and dykes of diabase. Only a small fragment of a volcanic district has survived at St. David's. The centre of eruption probably lay somewhere to the south-west.

While volcanic action, though never so vigorous as in later geological times, manifested itself over most of Wales and probably across what is now the centre of England, there is, I think, evidence that its extreme western limits reached as far as the east of Ireland. The rocks of Howth Island to the north of Dublin and of Bray

Head to the south have long been recognized as equivalents of some part of the Cambrian system of Wales; and though Mr. Blake would make them older and place them in his "Monian System"*, I see no good reason for questioning the received opinion on the subject.

The grits, quartzites, and shales or slates of Howth have, on the whole, an inclination towards the south, so that the lowest parts of the section are to be looked for at the north end. By far the most remarkable members of this group of strata occur towards the base. They consist of beds of breccia, regularly banded with the other strata, on many successive horizons, composed of a grey shaly matrix through which are dispersed in variable quantity angular, subangular, and more rarely rounded pieces of grit, quartzite, and shale, varying in size up to a foot in diameter. The coarsest beds lie towards the bottom, and the included stones become fewer and smaller as the strata are followed in upward sequence until we come to bands with only a single stone stuck here and there in the shaly matrix. The fragments are exactly like pieces of the ordinary strata of the island. Were the occurrence of these breccias an unique phenomenon, one would hesitate to assign an origin to them; but their resemblance to a certain class of volcanic breccias in other Palæozoic formations leads me to regard them as probably due to contemporary volcanic explosions whereby older portions of the Cambrian deposits of this region were blown out so as to fall in fragments on the sea-floor and be entombed in later accumulations of the same system.

The evidence obtainable at Bray is less striking, but possibly not less important. The rocks of this promontory, though not precisely like those of Howth, doubtless form part of the same series. I could not find there any trace of the coarse breccias of the more northern locality; but I observed numerous intercalations of a peculiar dull, pale olive-green or greenish buff-coloured, exceedingly fine-grained felsitic material which can be recognized, even from a little distance, by its weathering with a characteristic rough cavernous or carious surface, which contrasts with the smoother joint-faces of the shales and grits. This substance occurs in laminæ and bands from less than a line to occasionally as much as a foot in thickness among the shales and grits, but more especially among the former. It resembles some of the fine felsitic tuffs of Bangor and Llanberis and those in the Lower-Silurian series of Wicklow and

* Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 534.

Wexford. It occurs at wholly irregular intervals—sometimes in numerous bands lying close together within a space of a few yards, while elsewhere it may be absent for equal or longer spaces.

Judging of this material in the field, I regarded it as probably a fine impalpable volcanic dust erupted at irregular intervals by comparatively feeble explosions from vents lying at some considerable distance from Bray. An examination of it under the microscope throws no satisfactory light on its origin, the material appearing so perfectly homogeneous and structureless that, merely from the slides themselves, one might be left in doubt whether the rock is not an exceedingly close-grained felsite.

## V. SILURIAN.

### i. Arenig Period—Merionethshire.

Placing the upper limit of the Cambrian system at the top of the Tremadoc group, we pass now into the records of another series of volcanic eruptions which marked various epochs during the Silurian period over the area of the British Isles. The earliest of these volcanic episodes has left its memorials in some of the most impressive scenery of North Wales. To the picturesque forms sculptured out of the lavas and ashes of that early time we owe the noble range of cliffs and peaks that sweeps in a vast semicircle through the heights of Cader Idris, Aran Mawddwy, Arenig, and Moel Wyn. To the east other volcanic masses, perhaps in part coeval with these, rise from amidst younger formations in the groups of the Berwyn and Breidden Hills, and the long ridges of the Shelve and Corndon country. Far to the south traces of the older Silurian volcanoes are met with near Builth, while still more remote are the sheets of lava and tuff interstratified among the Lower-Silurian rocks of Pembrokeshire which extend even into Skomer Island.

The most important of these districts is unquestionably that of Merionethshire. In this area there is no evidence of any volcanic period older than that to which I have now to refer. Neither in the slaty Lingula Flags and the Menevian group nor in the vast pile of grits and conglomerates in the Harlech anticline does there appear to be any trace of contemporaneous volcanic action. If any earlier eruptions preceded those of Cader Idris and the other hills, their memorials had been buried under more than 10,000 feet of sediment before the emission of the tuffs and lavas of Merionethshire.

At the time when the Geological-Survey maps of this region were

prepared the Cambrian and Lower-Silurian rocks had not been subdivided into the various palæontological groups which are now recognized. Nor had any attempt been made to separate the various kinds of contemporaneous igneous masses from each other and from the tuffs in so extensive and complicated a mountain-region. The task undertaken by the Survey was beset with difficulties, some of which geologists, furnished with the advantages of a later time, can hardly perhaps realize. The imperfections of the mapping were long ago recognized by the original surveyors, and various corrections of them were made from time to time. First of all, the volcanic rocks which originally had been all massed under one colour were traced out separately on the ground according to their structure and mode of origin, and were distinguished from each other on the map *. Subsequently divisional lines were followed out between some of the larger stratigraphical groups, the maps and sections were still further modified, and the results were summed up in the second edition of the volume on the Geology of North Wales †. But short of actually re-surveying the whole of that rugged tract, it was impossible to bring the maps abreast of the onward march of science. They consequently remain, as a whole, very much as they were some thirty or forty years ago.

Sir Andrew Ramsay, in his great Monograph, has described the Merionethshire volcanic district in considerable detail. He seems finally to have come to the conclusion that the eruptions of that area were included within the Arenig period ‡. He shows, indeed, that on Rhobell Fawr the ejected materials lie directly on disturbed Lingula Flags without the intervention of the Tremadoc group, which is nevertheless present in full development in the near neighbourhood. And in trying to account for this remarkable fact he evidently had in his mind the possibility that volcanic eruptions had taken place long before as well as after the beginning of the deposition of the Arenig grit and slates §. He seems eventually, however, to have looked on the Rhobell-Fawr sections as exceptional and possibly to be accounted for by some local disturbance and intrusion of eruptive rock. He clearly recognized that there were two

* Mem. Geol. Surv. vol. iii. 2nd edit. p. 95, note.

† Some of the modifications introduced are, I think, to be regretted, for the earlier editions of the maps and sections are in certain respects more accurate than the later. On this point I concur with the criticism made by Messrs. Cole and Jennings, Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 436.

‡ Mem. Geol. Survey, vol. iii. 2nd edit. p. 96.

§ *Op. cit.* p. 72.

great epochs of volcanic activity during the Silurian period in Wales, one belonging to the time of the Arenig, the other to that of the Bala rocks, and he pointed out that the records of these two periods are separated by a thick accumulation of sedimentary strata which, being free from interstratifications of contemporaneous igneous rocks, mark a long interval of quiescence among the subterranean forces *.

The lower limit of the Arenig rocks has been fixed at a band or bands of grit or conglomerate which can be followed with some slight interruptions all round the great dome of Cambrian strata from Llanegrin on the south to the shore at Criccieth on the north. The volcanic group doubtless lies, generally speaking, above that basement platform. But, besides the sections at Rhobell Fawr just referred to, where the volcanic materials lie on the Lingula Flags, the same relation may, I think, be observed on the north flank of Cader Idris. Messrs. Cole, Jennings, and Holland have come to the conclusion that the eruptions began at a rather earlier date than that assigned to them in the Survey Memoirs, and my own examination of the ground leads me to accept their conclusion †. I believe that the earliest discharges in the southern part of the region took place at the close of the deposition of the Lingula Flags, and that intermittent outbursts occurred at many intervals during the time when the Tremadoc and Arenig rocks were deposited.

An upper limit to the volcanic group is less easily traceable, partly, no doubt, from the gradual cessation of the eruptions and partly from the want of any marked and persistent stratigraphical horizon near the top of the group. Sir Andrew Ramsay, indeed, refers to the well-known band of pisolitic iron-ore as lying at or near to the top of the Arenig rocks ‡. There can be no doubt, however, that the volcanic intercalations continue far above that horizon in the southern part of the district.

In spite of the extent to which the volcanic masses of this ancient period have been covered by later Palæozoic formations, it is still possible to fix approximately the northern, western, and southern limits of the district over which the ashes and lavas were distributed. These materials die out as they are traced southwards from Cader Idris and north-westwards from Tremadoc §. The greatest diameter of ground across which they are now continuously traceable is about

* *Op. cit.* pp. 71, 96, 105.

† Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 436; Geol. Mag. (1890) p. 447.

‡ Mem. Geol. Survey, vol. iii. 2nd edit. pp. 249, 250.

§ *Op. cit.* p. 96.

twenty-eight miles. They attain their maximum of thickness, upwards of 5000 feet, in Aran Mawddwy, which rises from their most easterly escarpment. We may therefore infer that the main vent or vents lay somewhere in that direction. The noble range of precipices facing westwards shows how greatly the limits of the volcanic rocks have been reduced by denudation. There can be little doubt that at least the finer tuffs extended westwards as far as a line drawn from Tremadoc to Llanegrin—that is, some fifteen miles or more beyond the cliffs of Aran Mawddwy, thus stretching across much of the site of what is now the great Harlech anticline.

This compact, well-defined volcanic area, in spite of the faults which traverse it and the disturbed positions into which its rocks have been thrown, is, in many respects, one of the simplest and most easily studied among the Palæozoic formations of this country. Its main features have been delineated on the maps of the Geological Survey and have been described in the Memoir. But these publications cannot be regarded as more than a first broad, though masterly, outline of the whole subject. There is an ample field for further and more minute research wherein, with the larger and better Ordnance maps now available, and with the advantage of the numerous modern petrographical aids, a more exhaustive account may be given of the district. The whole volcanic succession from base to summit is laid bare in innumerable magnificent natural sections along ranges of hills for a distance of some forty miles, and a careful study and re-mapping of it could not fail to add greatly to our knowledge of the early history of volcanic action *.

According to the observations of the Geological Survey, the volcanic rocks of Merionethshire naturally arrange themselves in three great bands, each of which is described as tolerably persistent throughout the whole district:—1st. A lower series of ashes and conglomerates, sometimes 3300 feet thick (Aran Mawddwy); 2nd. A middle group of "felstones" and "porphyries," consisting partly of true contemporaneous lava-streams and partly of intrusive sheets, and reaching a thickness of 1500 feet; 3rd. An upper series of fragmental deposits like that beneath, the extreme thickness of which is 800 feet (Arenig). A re-mapping of the ground on the six-inch maps would, no doubt, show many local departures from this general scheme.

* The excellent conjoint papers of Professor Cole, Mr. Jennings, and Mr. Holland are, I hope, an earnest of what may be expected from them in their examination of this deeply interesting region

The pyroclastic members of this volcanic series present many features of interest both to the field-geologist and the petrographer; but they have as yet been only partially studied. At the southern end of the district it is remarkable to what a large extent the earliest eruptions must have been mere gaseous explosions, with the discharge of comparatively little volcanic material. Many of the tuffs that are interstratified with black slates (? Lingula Flags), at the foot of the long northern slope of Cader Idris, consist mainly of black-slate fragments like the slate underneath, with a variable proportion of grey volcanic dust. Some of these bands of tuff are less than an inch thick, and they follow each other at frequent intervals. The first glimpse we thus get of the volcanic history of this part of Wales shows us a continued series of feeble gaseous discharges from probably many small vents, whereby the black clay on the sea-floor was blown out, the fragments falling back again to be covered up under the gradual accumulation of similar dark mud.

But elsewhere, and likewise at a later period, in this same southern part of the district, the fragmental discharges consisted mainly of volcanic material. Sir Andrew Ramsay has described the coarse conglomerates composed of subangular and rounded blocks of different "porphyries," sometimes twenty inches in diameter, embedded in a fine matrix of similar materials. The true nature of the component fragments in these and similar rocks has still to be worked out.

Messrs. Cole and Jennings have noticed that the grey volcanic dust of the older slate-tuff of Cader Idris is seen under the microscope "to abound in particles of scoriaceous andesite-glass, now converted into a green palagonite;" and they found abundant traces of andesitic lavas among the tuffs and conglomerates of Rhobell Fawr *. Their investigations show that while the same kinds of volcanic rocks continue to be met with from the bottom to the top, nevertheless there is an increase in the acid character of the lapilli as the section is traced upwards. Some of the fragments consist of colourless devitrified glass with pieces of pumice, as if derived from the breaking up of previously-formed tuffs. Others resemble quartz-andesites, rhyolites, or trachytes, while in at least one instance, somewhat low down in the section, quartz-grains with intruded material point to the existence of some fairly acid and vitreous lava †. On the south side of Llyn Cau, that is towards the top of the volcanic

* Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 424; Geol. Mag. (1890) p. 447.

† *Op. cit.* p. 429. A tuff lying below the ironstone near Cross Foxes, east of Dolgelly, likewise contains fragments of trachytic lavas.

group, I found a coarse agglomerate with blocks of felsitic lavas, sometimes three feet across. This gradual increase of acidity in the lapilli of the tuffs finds an interesting confirmation in the contemporaneous lava-sheets to which I shall afterwards allude.

One of the most noticeable features in the tuffs of this volcanic group is the great abundance of entire and broken crystals dispersed through them. These crystals have certainly not been formed *in situ*, but were discharged from the vents as part of the volcanic dust. They usually consist of felspar which, at least in the southern portion of the district, appears generally to be plagioclase. Frequent reference to these crystals as evidence of volcanic explosions may be found in the publications of the Survey. Nowhere can they be better seen than in the black slate-tuffs of Cader Idris. They are there white, more or less kaolinized, and as they lie dispersed through the black base they give the rock a most deceptive resemblance to some dark porphyry. On Rhobell Fawr, on the other hand, large crystals, broken and entire, of hornblende are abundantly scattered through much of the tuff.

In the central parts of the district thick bands of ashes were mapped by the Survey and described as consisting almost wholly of volcanic materials, but containing occasional thin bands of slate which suffice to mark pauses in the eruptions, when ordinary sediment was strewn over the sea-bottom. In the Cader Idris ground, on the other hand, interstratifications of non-volcanic material are of such frequent recurrence as to show that there, instead of constant and vigorous discharges accumulating a vast pile of ashes, the eruptions followed each other after intervals of sufficient duration to allow of the usual dark sediment spreading for a depth of many feet over the sea-bottom. One of the most interesting deposits of these interludes of quiescence is that of the pisolitic ironstone and its accompanying strata on the north front of Cader Idris. A coarse pumiceous conglomerate with large slag-like blocks of andesite and other rocks seen near Llyn y Gadr, passes upward into a fine bluish grit and shale, among which lies the bed of pisolitic (or rather oolitic) ironstone which is so widely diffused over North Wales. The finely oolitic structure of this band is obviously original, but the substance was probably deposited as carbonate of lime under quiet conditions of precipitation. The presence of numerous small *Lingulæ* in the rock shows that molluscan life flourished on the spot at the time. The iron exists in the ore mainly as magnetite, the original calcite or aragonite having been first replaced by carbonate

of iron, which was subsequently broken up so as to leave a residue of minute cubes of magnetite *.

Above the ironstone some more blue and black shale and grit pass under a coarse volcanic conglomerate like that below, lying at the base of the high precipice of Cader Idris. Hence this intercalated group of sedimentary strata marks a pause in the discharge of ashes and lavas, during which the peculiar conditions of sedimentation indicated by the ironstone spread over at least the southern part of the volcanic area. Some few miles to the east, where the ironstone has been excavated near Cross Foxes, the band is again found lying among tuffs and grits full of volcanic lapilli.

Between a lower and an upper band of tuff in the Arenig volcanic group the maps and Memoir of the Geological Survey distinguish a central zone of "felspathic porphyry," which attains a maximum thickness of 1500 feet. From Sir Andrew Ramsay's descriptions, it is clear that he recognized in this zone both intrusive and extrusive sheets, and that the latter, where thickest, were not to be regarded as one mighty lava-flow, but rather as the result of successive outpourings, with occasional intervals marked by the intercalation of bands of slate or of tuff. To a certain extent the intruded sheets are separated on the map from the contemporaneous lavas; but this has been done only in a broad and sketchy way. One of the most important, and at the same time most difficult, tasks yet to be accomplished in this district is the separation of the rocks which were probably poured out at the surface from those that were injected underneath it. My own traverses of the ground have convinced me that good evidence of superficial outflow may be found in tracts which have been mapped as entirely intrusive; while, on the other hand, some of the so-called "lavas" may more probably be of the nature of sills.

The petrography of the rocks, moreover, is as yet almost untouched. Among the so-called "felspathic porphyries" of the Survey maps a considerable variety of texture, structure, and composition will doubtless be detected. In the "Descriptive Catalogue of Rock-Specimens in the Museum of Practical Geology" (3rd edition, 1862) the rocks that form the "lava-streams of Llandeilo age" in Merionethshire are named "felstone," "felspar-porphyry," "felstone-porphyry," "felspathic porphyry," and "calcareous amygdaloid."

The most interesting feature which my own slight personal acquaintance with the ground has brought before me is the clear evidence of a succession from comparatively basic lavas in the lower

* Cole and Jennings, *op. cit.* p. 426.

part of the group to much more acid masses in the higher part. In the Survey map numerous sheets of intrusive "greenstone" are shown traversing the Lingula Flags, Tremadoc slates, and lower part of the volcanic group along the northern slopes of Cader Idris. The true intrusive nature of much of this material is clearly established by transgressive lines of junction and by contact-metamorphism, as well as by the distinctive crystalline texture of the rocks themselves. But the surveyors were evidently puzzled by some parts of the ground. Sir Andrew Ramsay speaks of "the great mass of problematical vesicular and sometimes calcareous rock which is in places almost ashy-looking." After several oscillations of opinion, he seems to have come finally to the conclusion that this vesicular material, which occurs also in the upper part of the mountain, passes into and cannot be separated from the undoubted intrusive "greenstones" *.

The true solution of the difficulty will be found, I believe, in the recognition of a group of scoriaceous lavas among these greenstones. The presence of a cellular structure is not unknown among dykes, but, so far as my experience goes, it is comparatively rare among sills, and when met with in these, occurs rather locally. That some of these Cader-Idris amygdaloids were really poured out at the surface can be demonstrated from the volcanic conglomerates associated with them. Below Llyn y Gadr—the dark tarn at the foot of the vast wall of Cader Idris—the beds of coarse volcanic conglomerate, to which I have already alluded, are largely composed of blocks of the vesicular "greenstones" on which they lie. These "greenstones," moreover, have many of the most striking characteristics of true lavas. They are extraordinarily cellular, their upper surfaces sometimes present a mass of bomb-like slags with flow-structure, and the vesicles are not infrequently arranged in rows and bands along the dip-planes.

A microscopic examination of two slides cut from these rocks shows them to be of a trachytic or andesitic type, with porphyritic crystals of a kaolinized felspar embedded in a microlithic groundmass. The rocks are much impregnated with calcite, which fills their vesicles and ramifies through their mass.

A few miles to the east some remarkable felsitic rocks take the place of these vesicular lavas immediately below the pisolitic iron-ore. I have not determined satisfactorily their relations to the surrounding rocks, and in particular am uncertain whether they

* Mem. Geol. Survey, vol. iii. 2nd ed. p. 36; see also pp. 31, 32.

are interbedded lavas or intrusive sheets. Dr. Hatch finds that their microscopic characters show a close resemblance to the soda-felsites described by him from the Bala series of the south-east of Ireland.

The remarkably cellular rock which forms the peak of Cader Idris is coloured on the Survey map as an intrusive sill of "greenstone," which in the Memoir is said to alter the contiguous slates and to appear to cut across them diagonally. I am disposed, however, to think that these appearances of intrusion are possibly deceptive. On the southern declivity of the mountain this rock presents one of the most curious structures to be seen in the whole district. Its surface displays a mass of spheroidal blocks aggregated together, each having a tendency to divide internally into prisms which diverge from the outside towards the centre. Some portions are extremely slaggy, and round these more solid portions finely crystalline parts are drawn, suggestive rather of free subaerial motion than of the conditions under which a subterranean sill must be formed. The idea occurred to me on the ground that while the band of rock marked as "greenstone" on the map is probably, in the main, an interstratified lava, there may nevertheless be basic intrusions along its course, as in the lower part of the mountain.

The minute structure of this amygdaloid, as revealed by the microscope, shows it to be an epidiorite wherein the hornblende, paramorphic after augite, has been again partially altered along the margins into chlorite.

The highest lavas of Cader Idris, forming the ridge to the south of Llyn Cau, are separated from the amygdaloid just described by a thick zone of black slate with thin ashy intercalations, beyond which comes the coarse volcanic agglomerate already referred to as containing blocks of felsite a yard or more in diameter. These lavas are true felsites, sometimes beautifully spherulitic and exhibiting abundant flow-structure, like some of the felsites of the next or Bala volcanic period *. The petrography of these rocks still remains to be worked out.

Hardly any information has yet been obtained as to the situation

* Cole and Jennings. Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 430. From the examination of slices prepared from a few of the felsites of the Dolgelly district, Dr. Hatch has observed a 'striking difference between their characters and those of the Cambrian felsites of Caernarvonshire. The porphyritic constituent is now no longer quartz but felspar (plagioclase), and the rocks belong not to the rhyolitic but rather to the less acid trachytes, perhaps even to the andesites.'

and character of the vents from which the lavas and ashes of Merionethshire were discharged. In the course of the mapping of the ground the Geological Survey recognized that, as the greatest bulk of erupted material lies to the east and south-east of the region, the chief centres of emission were to be looked for in that quarter, and that possibly some of the intrusive masses which break through the rocks west of the great escarpment may mark the site of vents, such as Tyddyn-rhiw, Gelli-llwyd-fawr, Y-Foel-ddu, Rhobell Fawr, and certain bosses near Arenig *. The distribution of the volcanic materials indicates that there were certainly more than one active crater. While the southward thickening of the whole volcanic group points to some specially vigorous volcano in that quarter, the notable thinning away of the upper tuffs southward and their great depth about Arenig suggest their having come from some vent in this neighbourhood. On the other hand, the lower tuffs are absent at Arenig, while on Aran Mawddwy, only nine miles to the south, they reach a depth of 3000 feet. Still farther to the south these volcanic ejections become more and more divided by intercalated bands of ordinary sediment. One of the most important volcanoes of the region evidently rose somewhere in the neighbourhood of what is now Aran Mawddwy. There seems reason to surmise that the sites of the chief vents now lie to the east and south of the great escarpment, buried under the thick sedimentary formations which cover all that region. If we are justified, on stratigraphical and petrographical grounds, in connecting the volcanic rocks of the Berwyn range with those of Merionethshire, we may speculate on the existence of a group of submarine vents coming into eruption at successive intervals from the close of the period of the Lingula Flags up almost to that of the Bala rocks, and covering with lavas and ashes a space of sea-bottom at least forty miles from east to west by more than twenty miles from north to south, or roughly an area of some 800 square miles.

But besides the materials ejected to the surface, this ancient volcanic region was marked by the intrusion of a vast amount of igneous rock between and across the bedding-planes of the strata deep underground. One of the most prominent features of the Geological-Survey map is the great number of sills represented as running with the general strike of the strata, especially between the top of the Harlech grits and the base of the volcanic series. On the north side of the valley of the Mawddach, between

* Mem. Geol. Survey, vol. iii, 2nd ed. p. 98 ; see also pp. 44, 54, 58, 71.

Barmouth and Rhaiadr Mawddach, in a distance of twelve miles the Survey mapped "more than 150 intrusions varying from a few yards to nearly a mile in length" *. This zone of sills is equally marked on the south side of the valley. It may be traced all round the Harlech anticline until it dies out, as the bedded masses also do, towards Towyn on the south and round about Tremadoc on the north.

The presence of such a zone of intrusive sheets at the base of an ancient volcanic series has been noted in various parts of Britain and in rocks of different geological ages up to the Tertiary basaltic plateaux of Antrim and the Inner Hebrides. But nowhere, perhaps, is it so strongly developed as beneath the Arenig group of lavas and tuffs in North Wales. Abundant as are the protrusions marked on the Geological-Survey map, they fall short of the actual number to be met with on the ground. Indeed, to represent them as they really are would require laborious surveying and the use of maps on a far larger scale than one inch to a mile.

The vast majority of these sills are basic rocks or, in the old and convenient terminology, "greenstones." Those of the Cader-Idris district have been examined by Messrs. Cole and Jennings, who find that, notwithstanding the considerable alteration everywhere shown by the abundant epidote and calcite, the coarser varieties may be recognized as having originally been dolerites approaching gabbro, with a well-developed ophitic structure, the general range of structure being from dolerites without olivine and aphanites to andesitic rocks with an originally glassy matrix †. Dr. Hatch confirms this diagnosis from the slides prepared from my specimens. The ophitic structure is usually characteristic and well preserved, in spite of the alteration indicated by epidote, chlorite, uralite, and leucoxene.

That this zone of "greenstone" sills belongs to the period of the Merionethshire volcanoes does not admit of serious doubt. The way in which they follow the line of the great escarpment, their almost entire absence from the Cambrian dome to the west, their cessation as the overlying lavas and tuffs die out, and their scarcity above the lower part of the volcanic group, show their close relationship to that group. Moreover, that they must have been as a whole later than the main part of the lavas and tuffs may be confidently inferred from their position. The molten material of which they were formed could not have forced its way between and across the strata unless egress to the surface had been impeded by some thick

* Mem. Geol. Survey, vol. iii. 2nd ed. p. 26.

† Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 432.

overlying mass. The "greenstones" may therefore be regarded as lateral emanations from funnels of more basic lava towards the close of the volcanic period. Possibly some at least of the highly slaggy and vesicular bands to which I have referred may represent portions of this material, which actually flowed out as streams of lava at the surface.

But there is likewise evidence of extensive intrusion of the more siliceous rocks. On the Geological-Survey map, besides the numerous "greenstones," various sheets of "felspathic porphyry" are represented as running with the general strike of the region, but here and there breaking across it. One of the most remarkable of these acid sills is that which in the noble precipice of Cader Idris has a thickness of about 1500 feet and a length of three or four miles. It is shown on the map to be transgressive across other rocks and, as seen on the ground, it maintains the uniformity of texture which is characteristic rather of sheets that have solidified underneath than of those which have congealed with comparative rapidity at the surface. On a fresh fracture the rock presents a pale bluish-grey tint, becoming yellowish or brownish as the result of weathering. Its texture is finely granular, with occasional disseminated felspars. Under the microscope a section of it was found by Dr. Hatch to exhibit the characteristic structure of a microgranite, a confused holocrystalline aggregate of quartz and felspar, with a few porphyritic felspars. Messrs. Cole and Jennings have proposed to revive for this rock Daubuisson's name "Eurite"*.

A similar rock occurs at a lower horizon among the Lingula Flags at Gelli-llwyd-fawr, two miles south-west of Dolgelly †, and much microgranite has been injected along the slopes above Tyddyn-mawr.

With these and other intrusions the granite should perhaps be considered which rises as an oblong boss-like mass a little to the north of Festiniog.

I am not aware that the chronological relation of these acid sheets and bosses to the more basic intrusions has yet been definitely determined. That some of them may have solidified in vents and may have been directly connected with the protrusion of the later or more highly siliceous lavas is not at all improbable.

The remarkable scarcity of dykes in the volcanic districts of Wales has been noticed by more than one observer. Among the intrusive "greenstones" of Merionethshire some occasionally

* Mr. Harker speaks of the rock as a granophyre.

† Cole and Jennings, *op. cit.* p. 435.

assume the dyke form, and through the agglomerates and tuffs of Rhobell Fawr dykes of olivine-diabase have worked their way. But there has been no widespread fissuring of the ground and uprise of lava in the rents, such as may be seen in the Archæan gneiss, and in the later Palæozoic, but still more in the Tertiary volcanic regions. This feature becomes all the more notable when it is viewed in connexion with the extraordinary development of sills, and the evidence thereby afforded of widespread and extremely vigorous subterranean volcanic action.

In the Merionethshire region there certainly was a long period of quiescence between the close of the Arenig and the beginning of the Bala eruptions. Moreover, no evidence has yet been found that active vents ever again appeared in that district, the subterranean energy at its next outburst having broken out farther north. In Anglesey, however, where, as I shall point out, there is proof of contemporaneous tuffs among the Arenig rocks, it is possible that a continuous record of volcanic action may yet be traced from Arenig well onward into Bala time. I reserve some notice of this subject for the account which I shall give of the Bala volcanic rocks of Anglesey.

### II. Llandeilo and Bala Periods—(*a*) Caernarvonshire, Anglesey.

Owing to the effects partly of plication and partly of denudation, the rocks of the next volcanic episode in Wales, that of the Bala period, occupy a less compact and defined area than those of the Arenig group in Merionethshire. From the latter they are separated, as we have seen, by a considerable depth of strata *, whence we may infer, with the Geological Survey, that the eruptions of Arenig, the Arans, and Cader Idris were succeeded by a long period of repose. When the next outbreaks took place the vents, as I have said, are found to have shifted northwards into Caernarvonshire, where they fixed themselves along a line not much to the east of where the Cambrian porphyries and tuffs now appear at the surface. The lavas and ashes that were thrown out from these vents form the highest and most picturesque mountains of North Wales, culminating in the noble cone of Snowdon. They stretch northwards to Diganwy, beyond Conway, and southwards, at least as far as the neighbourhood of Criccieth. They die out

* Estimated at from 6000 to 7000 feet. Mem. Geol. Surv. vol. iii. 2nd edit. p. 131.

north-eastwards beyond Bala Lake, and there can be but little doubt that they thin out also eastwards under the Upper-Bala rocks. The lavas and tuffs that rise up on a similar horizon among the Bala rocks of the Berwyn Hills evidently came, not from the Snowdonian vents, but from another minor volcanic centre some miles to the east, while still more remote lay the vents of the Breidden Hills and the sheets of andesitic tuff that probably spread from them over the ground east of Chirbury.

Restricting myself for the present to the Caernarvonshire volcanic group, I may remark that it extends from north to south for fully thirty miles, with an extreme breadth of about fifteen miles; while, if we include the rocks of the Lleyn peninsula, the area will be prolonged some twenty miles farther to the south-west.

The general stratigraphical horizon of this volcanic group has been well determined by the careful mapping of Ramsay, Selwyn, and Jukes on the maps of the Geological Survey. These observers have brought forward ample evidence to show that the lavas and tuffs were erupted during the deposition of the Bala strata of the Lower-Silurian series, that the Bala Limestone is in places full of ashy material, and that this well-marked fossiliferous band passes laterally into stratified volcanic tuffs containing the same species of fossils *. But the progress of stratigraphical geology, and the increasing value found to attach to organic remains as marking even minor stratigraphical horizons, give us reason to believe that a renewed and still more detailed study of the Bala rocks of North Wales would probably furnish data for more precisely defining the platforms of successive eruptions, and would thus fill in the details of the broad sketch which Sir Andrew Ramsay and his associates so admirably traced. There may even be lithological horizons which, like the grit-band and pisolitic iron-ore of the Arenig group, might be capable of being followed among the cwms and crests as well as the opener valleys of Caernarvonshire. Until some such detailed mapping is accomplished, we cannot safely advance much beyond the point where the stratigraphy was left by the Survey.

From the Survey maps and sections it is not difficult to follow the general volcanic succession, and to perceive that the erupted materials must altogether be several thousand feet in thickness from the lowest lavas in the north to the highest on the crest of Snowdon. In that mountain the total mass of volcanic material is set down as

* Mem. Geol. Surv. vol. iii. 2nd edit. pp. 126, 128, 131, 139, &c.

3100 feet. But this includes only the higher part of the whole volcanic group. Below it come the lavas of Y Glyder Fach, which, according to the Survey measurements, are about 1500 feet thick, while still lower lie the ancient *coulées* of Carnedd Dafydd and those that run north from the vent of Y-foel-frâs, which must reach a united thickness of many hundred feet. We can thus hardly put the total depth of volcanic material at a maximum of less than 6000 to 8000 feet. The pile is of course thickest round the vents of discharge, so that no measurement, however carefully made at one locality, would be found to hold good for more than a short distance.

Though little is said in the Survey Memoir of the vents from which this vast amount of volcanic material was erupted, the probable positions of a number of these orifices may be inferred from the map. From the shore west of Conway a series of remarkable eminences may be traced south-westwards for a distance of nearly 40 miles into the peninsula of Lleyn. At the northern extremity of this line stands the prominent boss of Penmaen-mawr, while southward beyond the large mass of Y-foel-frâs, with the smaller knobs west of Nant Francon, and the great dome of Mynydd-mawr, the eye ranges as far as the striking group of *puy*-like cones that rise from the sea around Yr Eifl and Nevin. Some of these hills, particularly Y-foel-frâs, were recognized by the Survey as vents *. But the first connected account of them and of their probable relation to the volcanic district in which they occur has been given by Mr. Harker in his exceedingly able essay on "The Bala Volcanic Series of Caernarvonshire," †—the most important contribution to the volcanic history of Wales which has been made since the publications of the Geological Survey appeared. I shall refer to these vents more specially in the sequel. I allude to them here for the purpose of showing at the outset the marvellous completeness of the volcanic records of Caernarvonshire. So great has been the denudation of the region that the pile of lavas and tuffs which accumulated around and above these orifices has been entirely swept away. No trace of any portion of that pile has survived to the west of the line of bosses; while to the east, owing to curvature and subsequent denudation, the rocks have been dissected from top to bottom until almost every phase of the volcanic activity is revealed.

* *Op. cit.* pp. 137, 220.

† This was the Sedgwick Prize Essay for 1888, and was published in 1889.

The volcanic products discharged from these vents consist of a succession of lava-streams separated by bands of slate, tuff, conglomerate, and breccia. These fragmental intercalations, which vary from a few yards to many hundred feet in thickness, are important not only as marking pauses in the emission of lava or in the activity of the volcanoes, but as affording a means of tracing the several lavas to their respective vents. Essentially, however, the volcanic materials consist of lava-flows, the intercalations of fragmentary materials, though numerous, being comparatively thin. The thickest accumulation of tuffs is that forming much of the upper part of Snowdon. It is set down by my predecessor at 1200 feet in thickness, but I should be inclined to reduce this estimate considerably. I shall have occasion to show that the summit and upper shoulders of Snowdon are capped with andesites interstratified among the tuffs. Sir Andrew Ramsay has referred with justice to the difficulty of always discriminating in the field between the fine tuffs and some of the lavas *. Yet I am compelled to admit that, if the ground were to be re-mapped now, the area represented as covered by fragmental rocks would be considerably reduced. Mr. Harker is undoubtedly correct when he remarks that, taken "as a whole, the Bala Volcanic Series of Caernarvonshire is rather remarkable for the paucity of genuine ashes and agglomerates" †.

The lavas of the Bala volcanic group, like those of the Arenig series, were mapped by the Survey as "porphyries," "felstones," or "felspathic traps." They were shown to be acid-lavas, having often a well-developed flow-structure comparable with that of obsidian and pitchstone, and to consist of successive sheets that were poured out over the sea-floor. Their petrography has subsequently been studied more in detail by many observers, among whom I need only cite Professor Bonney, Professor Cole, Mr. Rutley, and Mr. Teall; the most recent, as well as the most important, additions to our knowledge of this subject having been made by Mr. Harker in the Essay to which I have already referred.

The great majority of these lavas are thoroughly acid rocks, and present close analogies of composition and structure to modern rhyolites, though I prefer to retain for them the old name of "felsites." Their silica percentage ranges from 75 to more than 80. To the naked eye they are externally pale greyish, or even white, but when broken into below the thick decomposed and decoloured margin

* *Op. cit.* p. 148.

† 'Bala Volcanic Rocks,' p. 25.

they are bluish grey to dark iron-grey, or even black. They break with a splintery or almost conchoidal fracture, and show on a fresh surface an exceedingly fine-grained, tolerably uniform texture, with minute scattered felspars.

One of their most striking features is the frequency and remarkable development of their flow-structure. Not merely as a microscopic character, but on such a scale as to be visible at a little distance on the face of a cliff or crag, this structure may be followed for some way along the crops of particular flows. The darker and lighter bands of devitrification, with their lenticular forms, rude parallelism, and twisted curvature, have been compared to the structure of mica-schist and gneiss. One aspect of this structure, however, appears to have escaped observation, or, at least, has attracted less notice than it seems to me to deserve. In many cases it is not difficult to detect, from the manner in which the lenticles and strips of the flow-structure have been curled over and pushed onward, what was the direction in which the lava was moving while still a viscous mass. By making a sufficient number of observations of this direction, it might in some places be possible to ascertain the quarter from which the several flows proceeded. As an illustration, I would refer to one of the basement-felsites of Snowdon, which forms a line of picturesque crags on the slope facing Llanberis. The layers of variously devitrified matter curl and fold over each other, and have been rolled into balls, or have been broken up and enclosed one within the other. The general push indicated by them points to a movement from the westward. Turning round from the crags, and looking towards the west, we see before us on the other side of the deep vale of Llyn Cwellyn, at a distance of little more than three miles, the great dome-shaped Mynydd-mawr, which, there is every reason to believe, marks one of the orifices of eruption. It might in this way be practicable to obtain information regarding even some of the vents that still lie deeply buried under volcanic or sedimentary rocks.

That these felsites were poured forth in a glassy condition may be inferred from the occurrence of those minute perlitic and spherulitic forms so characteristic of the devitrification of once vitreous rocks. Mr. Rutley was the first who called attention to this interesting proof of the close resemblance between Palæozoic felsites and modern obsidians, and other observers have since confirmed and extended his observations*.

* Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 508.

Another remarkable aspect of the felsites is that nodular structure so often to be seen among them, and regarding the origin of which so much has already been written. I agree with Professor Cole and Mr. Harker in looking upon the "nodules" as derived from original spherulites by a process of alteration, of which almost every successive stage may be traced until the original substance of the rock has been converted into a flinty or agate-like material. If this be the true explanation of the structure, some of the original lavas must have exhibited perlitic and spherulitic forms on a gigantic scale. There can, I think, be little doubt that this peculiar structure was very generally misunderstood by the earlier observers, who naturally looked upon it as of clastic origin, and who therefore believed that large beds of rock consisted of volcanic conglomerate which we should now map as nodular felsite (pyromeride) *.

While by far the larger proportion of the Caernarvonshire lavas are thoroughly acid rocks, the oldest outflows are much less so than those erupted at the height of the volcanic activity when the rocks of Snowdon were poured forth †. But towards the close of the period there was apparently a falling off in the acidity of the magma, for at the top of the group the andesitic lavas to which I have already alluded are encountered. Sir Andrew Ramsay has shown the existence of an upper "felstone" or "felspathic porphyry," almost entirely removed by denudation, but of which an outlier occurs on Crib-goch, Lliwedd, and other crests around Snowdon, and likewise on Moel Hebog ‡. Mr. Harker alludes to these remnants, and speaks of them as less acid than the older lavas, but he gives no details as to their structure and composition §. In a recent examination of Snowdon I was surprised to find that the summit of the mountain, instead of consisting of bedded ashes as hitherto represented, is formed of a group of lava-sheets having a total thickness of perhaps from 100 to 150 feet. The apex of Yr Wyddfa, the peak of Snowdon, consists of fossiliferous shale

* Another source of error may probably be traced in the occasional brecciated structure of the felsites, which has been mistaken for true volcanic breccia, but which can be traced disappearing into the solid rock. Sometimes this structure has resulted from the breaking up of the lenticles of flow, sometimes from later crushing.

† Harker, *op. cit.* p. 127.

‡ Mem. Geol. Surv. vol. iii. 2nd edit. pp. 141, 144, 145, 147, 161.

§ 'Bala Volcanic Series,' pp. 10, 23, 125. He refers also to lavas occupying a similar position at Nant Gwynant and Moel Hebog; but he adds that he had not had an opportunity of studying them.

lying on a dull grey rock that weathers with elongated vesicles, somewhat like a cleaved amygdaloid, but a good deal decomposed. A thin slice of this latter rock shows under the microscope irregular grains and microliths of felspar, with a few grains of quartz, the whole much sheared and calcified. Below this bed comes a felsite, or devitrified obsidian, showing in places good spherulitic structure, and followed by a grey amygdaloid. The latter is a markedly cellular rock, and, though rather decayed, shows under the microscope a microlithic felspathic groundmass, through which granules of magnetite are dispersed. Underneath this upper group of lavas lie the tuffs for which Snowdon has been so long celebrated. But, as I have already stated, there does not appear to me to be such a continuous thickness of fragmental material as has been supposed. There cannot, I think, be any doubt that not only at the top, but at many horizons throughout this supposed thick accumulation of tuff, some of the beds of rock are really lava-flows. Some of them have suffered considerably from the cleavage which has affected the whole of the rocks of the mountain, while the results of centuries of atmospheric disintegration, so active in that high exposed locality, have still further contributed to alter them. They consequently present on their weathered faces a resemblance to the pyroclastic rocks among which they lie. Where, however, the lavas are thicker and more massive, and have resisted cleavage better, some of them appear as cellular dull grey andesites or trachytes, while a few are felsites. Many instructive sections of such bands among the true tuffs may be seen on the eastern precipices of Snowdon above Glas-lyn.

It thus appears that the latest lavas which flowed from the Snowdonian vent were, on the whole, decidedly more basic than the main body of felsites that immediately preceded them. They occur also in thinner sheets, and are far more abundantly accompanied with ashes. At the same time it is deserving of special notice that among these less acid outflows there are intercalated sheets of felsite, and that some of these still retain the spherulitic structure formed by the devitrification of an original volcanic glass.

Far to the south-west, in the promontory of Lleyn, another group of volcanic rocks exists which may have been in a general sense contemporaneous with those of the Snowdon region, but which were certainly erupted from independent vents. Mr. Harker has described them as quartzless pyroxene-andesites, sometimes markedly cellular, and though their geological relations are rather

obscure, he regards them as lava-flows interbedded among strata of Bala age and occurring below the chief rhyolites of the district. If this be their true position, they indicate the outflow of much less highly siliceous lavas before the eruption of the acid felsites. In the Snowdon area any such intermediate rocks which may have been poured out before the time of the felsitic outflows have been buried under these.

The tuffs of the Bala series in Caernarvonshire have not received the same attention as the lavas. One of the first results of a more careful study of them will be a considerable modification of the published maps by a reduction of the area over which they have been represented. They range from coarse volcanic breccias to exceedingly fine compacted volcanic dust, which cannot easily be distinguished, either in the field or under the microscope, from the finer crushed forms of felsite. Among the oldest tuffs pieces of dark blue shale as well as of felsite may be recognized, pointing to the explosions by which the vents were drilled through the older Silurian sediments already deposited and consolidated. Sometimes, indeed, they recall the dark slate-tuffs of Cader Idris, like which they are plentifully sprinked with kaolinized felspar crystals. Among the beds of volcanic breccia intercalated between the lower felsites of Snowdon are magnificent examples of the accumulation of coarse volcanic detritus. The blocks of various felsites in them are often a yard or more in diameter. Among the felsite fragments smaller scattered pieces of andesitic rocks may be found. This mixture of more basic materials appears to increase upwards, the highest ashes containing detritus of andesitic lavas like those which occur among them as flows.

The tuffs in the upper part of Snowdon are well-bedded deposits made up partly of volcanic detritus and partly of ordinary muddy sediment *. Layers of blue shale or slate interstratified among them indicate that the enfeebled volcanic activity marked by the fine tuffs passed occasionally into a state of quiescence. As is well known, numerous fossils characteristic of the Bala rocks occur in these tuffs. The volcanic discharges are thus proved to have been submarine and to have occurred during Bala time.

I have already alluded to some of the probable vents from which the lavas and tuffs were discharged, and to their position along a line drawn from Penmaen-mawr into the peninsula of Lleyn. It

* See the interesting account of these tuffs given by Sir A. Ramsay, Mem. Geol. Survey, vol. iii. 2nd edit. p. 142.

will be observed that they lie outside the area of the bedded volcanic rocks and rise through parts of the Silurian system older than these rocks. The largest and most important of them is unquestionably that formed by Y-foel-fràs and its neighbouring heights. As mapped by the Geological Survey, this mass of igneous rock is irregularly elliptical, measures about six square miles in area, and consists mainly of intrusive "felstone-porphyry" passing into "hornblendic greenstone" *. Mr. Harker, however, has made an important correction of this petrography, by showing that a large part of the area consists of augitic granophyre, while the so-called "greenstone" is partly diabase and partly andesitic ashes and agglomerates. He suggests that an older vent has here been destroyed by a later and larger protrusion of igneous matter †. This high and somewhat inaccessible tract of ground is still in need of detailed mapping and closer study, for undoubtedly it is the most important volcanic vent now visible in North Wales. My colleague in the Survey, Mr. E. Greenly, spent a week upon it a few years ago, and he has been good enough to supply me with the following notes of his observations :—The central and largest area of the neck is mainly occupied with diabases and andesites, while the ashes and agglomerates which are intimately connected with them seem to run as a belt or ring round them, and to occur in one or more patches in the midst of them. Portions of green amygdaloid run through the pyroclastic masses. Outside the ring of agglomerate and ashes an interrupted border of felsite can be traced, which may be presumed to be older than they, for a block of it was observed in them. The granophyre, on the other hand, which is interposed between the fragmental masses and the surrounding rocks on the western wall of the vent, seems to be of later date. Dykes or small bosses of diabase, like the material of the sills, pierce both the agglomerates and the rocks of the centre ‡.

No agglomerate appears to have been noticed by any observer among the other supposed vents along the line that runs south-westwards from Penmaen-mawr, until we reach the south-western end of the line in the promontory of Lleyn. The vents are rudely circular bosses rising vertically out of the Lower-Silurian or Cam-

* Mem. Geol. Survey, vol. iii. 2nd ed. pp. 137, 139.

† 'Bala Volcanic Series,' pp. 41, 71, 72, 123.

‡ Mr. Greenly has made a sketch map of this interesting locality, and I trust he may soon find an opportunity of returning thither and completing his investigations.

brian strata, or partake more of the nature of lenticular sheets or laccolites which have been thrust between the planes of bedding. There is usually an observable alteration of the surrounding rocks along the line of contact.

The material that now fills these vents is sometimes thoroughly acid, as is the granophyre of Y-foel-frâs, the microgranite of Mynydd-mawr with its riebeckite crystals, the augite-granite porphyry of Clynog-fawr, and the granophyric and rhyolitic quartz-porphyries of the Rivals. In other cases the rock is of an intermediate grade, as in the enstatite-diorite of Penmaen-mawr, the pyroxene-andesite of Carn Boduan, and the quartz-augite-syenite of Llanfoglen*. A few bosses of still more basic material occur in the Sarn district, including hornblende-diabase and hornblende-picrite. Sometimes both the acid and the more basic rocks are found in the same boss, as in the large mass of Y-foel-frâs.

It must be confessed that there is no absolute proof that any of these masses mark the actual sites of eruptive vents, except probably the boss of Y-foel-frâs. Some of them may have been intruded without establishing any outlet to the surface†. But that a few of them really represent orifices from which the Bala volcanic group was erupted may be plausibly inferred from their neck-like forms, from their positions with reference to the volcanic district, from the obvious thickening of the lavas and tuffs in the direction of these bosses, and from the petrographical relation that exists between their component materials and rocks that were discharged at the surface. This last-named feature has been well pointed out by Mr. Harker, who has established, by a study of microscopic slides, a gradation from the granophyric material of the bosses into structures greatly resembling those of the bedded felsites, and likewise a close similarity between the intermediate rocks of the other bosses and the porphyrites which have elsewhere been poured out at the surface ‡. But perhaps the most impressive evidence as to the sites of the chief centres of eruption is supplied by the lavas and tuffs themselves as they thicken in certain directions and thin away in others. This feature of their distribution has been well expressed in the maps and sections of the Survey, and has been clearly summarized by Mr. Harker §. The oldest lavas now visible

* The geological relations and petrographical characters of these various rocks are given by Mr. Harker in the fourth and fifth sections of his Essay.

† Mr. Harker speaks of some of them as laccolites.

‡ *Op. cit.* pp. 57, 72.

§ See especially pp. 9, 120, *et seq.*, and fig. 6 of his Essay.

lie at the northern end of the district, and the vents from which they proceeded may, with considerable probability, be placed somewhere in the tract which includes the chain of bosses of Penmaen-mawr, Y-foel-frâs, and Y Drosgl. The main mass of the eruptions no doubt took place somewhere in the Snowdon tract, where the lavas and tuffs attain their greatest thickness, and whence they thin away in all directions. The Mynydd-mawr boss may be presumed to have been one of the main vents. But there were not improbably others, now concealed under the deep cover of their own ejections.

More diligent search, with a special eye to the discovery of such vents, might indeed be rewarded, even in the midst of the volcanic district itself. To the north-east of Capel Curig, for example, there is a prominent knob of agglomerate *, which I visited with Mr. B. N. Peach, and which we regarded as probably marking one of the minor vents. The material of this eminence has a base which by itself would probably be regarded by the field-geologist as a felsite. But through this compact matrix are dispersed abundant stones of all sizes up to six inches or more in diameter. They are mostly subangular or somewhat rounded-off at the edges, and generally markedly-cellular. Among them may be observed pieces of trachyte, felsite, and a rock that is probably a devitrified pitchstone or obsidian. The vesicles in these stones are sometimes lined with an acicular zeolite. Traces of rude bedding can be detected, dipping at high angles. On the north-east side of the hill finer agglomerate is seen to alternate with ashy grits and grey shales, which, dipping E.N.E. at 20°–30°, pass under a group of felsites, one at least of which retains a very fine perlitic structure and evidently flowed as a true glass. Some of these lavas are full of enclosed pieces of various flinty cellular and porphyritic felsites and andesites or trachytes, like the stones which occur abundantly in the agglomerate. The connexion of these bedded lavas and tuffs with the agglomerate-neck seems obvious.

The Caernarvonshire volcanic area furnishes another admirable example of the intrusion of basic sills as a final phase of eruptivity. These masses have been carefully separated out on the maps of the Geological Survey, which present a striking picture of their distribution and their relation to the other igneous rocks. An examination of the maps shows at once that the basic sheets tend to lie parallel with the bedding along certain horizons. In the southern

* This rock is referred to in the Geological Survey Memoir as 'a short thick band of conglomeratic ash, which strikes northwards about half a mile and then disappears' (p. 134).

and western portions of the area they have forced themselves among the Lower-Silurian sedimentary strata that underlie the Bala volcanic group—a position analogous to that taken by the corresponding sills of the Arenig series. But they likewise invade the volcanic group itself. Along the eastern borders of the district they abound, especially in the higher parts of the volcanic group, where they have been injected between the flows and have subsequently participated in the abundant plication of the rocks between the mountains and the line of the River Conway.

The curvatures into which the rocks of the region have been thrown, and the consequent breadth of country over which the volcanic sheets can now be examined, furnish a much better field than in Merionethshire for the attempt to trace the probable centre or centres from which the basic magma was protruded. A study of the Survey maps soon leads to the conviction that the intrusions were not connected, except perhaps to a trifling extent, with the great line of western vents. It is remarkable that the older strata which emerge from under the volcanic group on its western outcrop are, on the whole, singularly free from sills, though some conspicuous examples are shown opposite to Mynydd-mawr, while a few more occur farther north along the same line. Their lenticular forms, their short outcrops, and their appearance on different horizons at widely separated points seem to indicate that the sills probably proceeded from many distinct subterranean pipes. Their greater abundance along the eastern part of the district may be taken to indicate that the ducts lay for the most part considerably to the eastward of the line of western vents. They may have risen in minor funnels, like that of Capel Curig.

It is remarkable that so abundant an extravasation of basic material should have taken place without the formation of numerous dykes. We have here a precise repetition of the phenomena that distinguished the close of the preceding Arenig volcanic period in Merionethshire. As the intrusion of an enormous amount of an igneous magma into the Earth's crust may thus take place without the formation of dykes, it is evident that the conditions for the production of sills must be in some important respects different from those required for dykes.

No evidence has yet been obtained that any one of these sills established a connexion with the surface. Not a trace can be found of the outpouring of any such basic lava-streams, nor have fragments of such materials been met with in any of the tuffs. On

the other hand, there is abundant proof of the usual contact-metamorphism. Though the sills conform on the whole to the bedding, they every here and there break across it. They swell out into thick irregular masses, and thin out rapidly. In short, they behave as true intrusive sheets, and not as bedded lavas.

In regard to their internal character, they show the customary uniformity of texture throughout each mass. They are mapped under the general name of "greenstones" by the Geological Survey, and are described in the Memoir as hornblendic*. The more precise modern methods of examination, however, prove them to be true diabases, in which the felspar has, as a rule, consolidated before the augite, giving as a result the various types of diabasic structure†.

The date of the intrusion of these basic sills can be fixed by the same process of reasoning as was applied to those of the Arenig volcanic group. Their connexion with the other igneous rocks of Caernarvonshire is so obvious that they must be included as part of the volcanic history of the Bala period. But they clearly belong to a late stage, perhaps the very latest stage, of that history. They could not have been injected into their present positions, unless a considerable mass of rocky material had overlain them. Some of them are certainly younger than the tuffs of Snowdon and Moel Hebog, which belong to a late part of the volcanic period. On the other hand, they had been intruded before the curvature and compression of the region, for they partake in the foldings and cleavage of the rocks among which they lie. The terrestrial movements that produced this disturbance have been proved to have occurred after the time when the uppermost Bala rocks were deposited, and before that of the accumulation of the Upper-Silurian formations ‡. The epoch of intrusion is thus narrowed down to some part of the Upper-Bala period. With this subterranean manifestation volcanic action in this part of the country finally died out.

I have already alluded to the Berwyn Hills as an independent volcanic area containing two groups of interbedded igneous rocks, of which the lower has been paralleled with the Arenig group of Merionethshire, while the upper is shown by its association with the Bala Limestone to be on the whole synchronous with the Snowdonian masses. But this area has not been worked out in greater detail

* *Op. cit.* p. 156. † Harker, 'Bala Volcanic Series,' p. 83.

‡ Mem. Geol. Survey, vol. iii. 2nd edit. p. 326. See also Mr. Harker's 'Bala Volcanic Series,' p. 76.

than is given in the Survey maps and Memoirs; and as I have not had an opportunity of visiting it myself, I pass it over for the present. In the Breidden Hills, and again in the country west of Corndon, andesitic tuffs and agglomerates, interstratified with the Bala beds, point to a distinct volcanic district still farther to the east *.

Let me now ask your attention to another part of the country, about which much has been written and keen controversy has arisen. In the centre of Anglesey, among the rocks grouped together by the Geological Survey as "altered Cambrian," there occur masses of agglomerate, the probable volcanic origin of which was, so far as I know, first clearly recognized by Professor Hughes †. Dr. Callaway regards them as pre-Cambrian, while Professor Blake places them in his "Monian system."

The agglomerates, well seen near Llangefni, contain abundant blocks of reddish quartzite, pieces of various felsites, and of finely amygdaloidal andesites. The matrix is a greenish material, such as might be derived from altered diabase detritus. Everywhere the rock presents evidence of having undergone enormous crushing and shearing. Its thin intercalated seams of quartzite have been broken down, and pieces of them have been carried along and isolated, so as to look like stones of the agglomerate. Bedding, though hardly traceable in the coarser parts, is easily made out elsewhere to be vertical by the intercalation of more solid strata and purple shaly interstratifications. It becomes more and more decided as the rocks are followed towards the north-west. Layers of red, purple, and greenish slate and pebbly grit intercalated in the volcanic conglomerates bear a close resemblance to parts of the volcanic series of Llyn Padarn and Bangor. A further point of similarity is supplied by the occurrence of bands of pale, compact, flinty tuffs like those that play so important a part in the Bangor group.

The relation of these rocks to the Lower-Silurian strata which immediately follow them to the north-west could not be satisfactorily determined in the traverses made by Mr. Peach and myself; but I could see no reason for believing them to belong to a different system. The kind of crushing which has so seriously

* See W. W. Watts on the igneous and associated rocks of the Breidden Hills, Quart. Journ. Geol. Soc. vol. xli. (1885) p. 532. The Arenig and Bala volcanic zones of the Corndon area have been worked out by Professor Lapworth, but his detailed account is not yet published.

† Proc. Camb. Phil. Soc. vol. iii. (1880) p. 347.

affected the volcanic rocks is precisely similar to that which the sedimentary strata immediately beyond them have suffered.

But though the required evidence may not be obtainable from this district of Anglesey, there is, I think, in other parts of the county sufficient proof that these volcanic rocks have no connexion with either of the two pre-Cambrian series to which I have already referred as existing in Anglesey, but belong to the Lower-Silurian groups. Seven miles to the south-east of Holyhead, in the basal Lower-Silurian conglomerates which Mr. Selwyn found lying unconformably on the green schists, there occur abundant fragments of volcanic rocks, besides the prevalent detritus of the schists of the neighbourhood. Some of the bands have somewhat the character of volcanic breccias or tuffs, and they show an evident resemblance to portions of the Bangor group and the rocks of Llyn Padarn, though they are doubtless of much later age. That these volcanic fragments were not derived from the waste of rocks of a much earlier period is made tolerably certain by the intercalation of true tuffs among the black shales higher up in the order of succession. Here, then, we have evidence of contemporaneous volcanic action in the very basement Lower-Silurian strata of Anglesey, which by their fossil contents are shown to be on the horizon of the lowest Arenig or even Tremadoc group. The Llangefni agglomerates may thus be connected with a Silurian volcanic period, and may have been brought into their present position by the general plication of the district.

But still further and more striking corroboration of this inference is to be obtained by an examination of the northern coast-line. I have already referred to the elliptical fault which is marked on the Survey map running from the north-western headland to the eastern coast beyond Amlwch. The necessity for inserting this fault, apart from any actual visible trace of its occurrence, arose when the conclusion was arrived at that the rocks of the extreme north of Anglesey were essentially altered Cambrian strata. For immediately to the south of these rocks black shales, obviously Silurian, were seen to dip to the north—a structure which could only be accounted for by a dislocation letting them down into that position. The same necessity for a fault has of course been felt by all writers who have subsequently treated the northern area as pre-Cambrian. But it is deserving of notice that in the original mapping of the Survey no continuous abrupt hiatus is shown by the line which was afterwards marked as a continuous line of fault. On the contrary,

on one of the field-maps in, I believe, Mr. Selwyn's handwriting the remark occurs:—"The gradual passage from the black shale to the upper green gritty slates of Llanfechell is best seen at Bothedd, on road from Llanfaethlu to Llyn-llygeirian."

It is no part of my aim to disprove the existence of faults along the line referred to. These may quite well exist; but there is assuredly no one gigantic displacement, such as the theory I am combating would require; while any faults which do occur cannot be greatly different from the others of the district, and do not prevent the true relations of the rocks from being discoverable.

Where the supposed elliptical fault reaches the shore at Carmel's Point, the two groups of rock seem to me to follow each other in unbroken sequence. The black slates, which are admittedly Lower Silurian, dip underneath a volcanic breccia and greenish (Amlwch) slates. Not only so, but bands of similar black slates occur higher up, interstratified with and shading-off into the tuffs and greenish slates. Further, bands of coarse volcanic breccia occur among the black slates south of the supposed break. These, in accordance with the exigencies of theory, are represented as separated by a network of faults from the black slates amid which they lie. But good evidence may be found that they are truly interbedded in these slates. In short, a critical examination of the sections shows that the whole of the rocks in that part of Anglesey form one great series, consisting partly of black slates, partly of greenish slates, with abundant intercalations of volcanic detritus. The age of the base of this series is moreover determined by the occurrence of Bala fossils in a band of limestone near Carmel's Point.

The rocks which extend eastward along the coast from the north-western headland of Anglesey are marked on the Survey map as "green, grey, and purple slates with conglomeratic and siliceous beds." The truly volcanic nature of a considerable proportion of these has been clearly stated by Mr. Blake *. As they dip in a general northerly direction, higher portions of the series present themselves as far as the most northern projections of the island near Porth Wen. They have been greatly crumpled and crushed, so that the slates pass into phyllites. They include some thick seams of blue limestone and white quartzite, also courses of black shale containing Lower-Silurian graptolites. Among their uppermost strata several (probably Bala) fossils, including *Orthis Bailyana*, have been obtained by Professor Hughes. It has been supposed that the higher

* Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 517.

bands of black shale may also have been brought into their present positions by faults, and that they do not really belong to the series of strata among which they lie. But this suggestion is completely disproved by the coast-sections, which exhibit many thin leaves of black shale sometimes less than an inch thick. These and the ashy layers containing the *Orthis* and other fossils form an integral part of the so-called "Amlwch slates."

It thus appears that the area coloured "altered Cambrian" on the Survey map, and regarded as pre-Cambrian by some later observers, is proved by the evidence of fossils at its base, towards its centre, and at its top to belong to the Lower-Silurian series, probably to the Bala division. That this was the geological horizon of part at least of the area was recognized by Sir A. Ramsay, though he confessed himself unable "precisely to determine on the north coast of Anglesey how much of the strata are of Silurian and how much of Cambrian age" *. Professor Hughes was the first to suggest that the whole of these rocks should be referred to the Bala group †.

I have dwelt on the determination of the true geological age of the rocks of the north of Anglesey because of the diversity of opinion respecting them, and because of their great interest in regard to the history of volcanic action in Wales. These rocks contain a record of volcanic eruptions, probably contemporaneous on the whole with those of the Bala period in Caernarvonshire, yet independent of them and belonging to a different type of volcanic energy. The vents lay in the northern half of Anglesey, where some of them can still be seen. The materials ejected from them were, so far as we know, entirely of a fragmentary kind. Vast quantities of detritus from the hugest blocks to the finest dust were thrown out; but though dykes rose up and filled fissures in the vents, no trace has yet been found of the outflow of any lava. In the lower part of this volcanic series the bedded breccias are remarkably coarse. Their included stones, ranging up to six inches or more in diameter, are usually more or less angular, and consist mainly of various felsites. Layers of more rounded pebbles occasionally occur, while the bedding is still further indicated by finer and coarser bands, and even by intercalations of fine tuffs and ashy shales. Towards their upper limits some of these volcanic bands shade off into pale grey or greenish ashy shale followed by black sandy shale of the usual kind.

* Mem. Geol. Surv. vol. iii. 2nd ed. p. 242.

† Proc. Camb. Phil. Soc. vol. iii. (1880) pp. 341–348.

The relation of the peculiar greenish shale of the Amlwch type to these tuffs and breccias is well shown east of Carmel's Point. This shale is interleaved with tuff and contains frequent repetitions of finer or coarser volcanic breccia, as well as occasional seams of black shale.

The breccias south of Carmel's Point, though they are chiefly made up o felsitic detritus, sometimes show a preponderance of fragments of shale. They vary also so rapidly in texture and composition as to suggest that the vent or vents from which their materials were derived must have stood somewhere in the near neighbourhood, if indeed they are not to be recognized in some of the boss-like eminences that rise above the coast. Some magnificent vents, however, have been actually laid open by the waves between Camlyn Bay and Cemmaes. One of these projects in the headland of Mynyddwylfa. It is filled with a coarse agglomerate, among the large blocks in which fragments of quartzite, limestone, felsite, grit, and shale may be noticed. Huge masses of stratified rock, including several beds still adhering to each other, have been torn up and thrown out by the volcano. Some of the blocks of quartzite and limestone are as large as cottages; one conspicuous limestone mass is at least thirty feet long. Dykes of dolerite ramify through the neck and cut across the embedded blocks. The earth-movements which have so powerfully affected the stratified rocks of the district have likewise produced their effects here, superinducing on the agglomerate a rude cleavage in the same general direction as that of the cleavage in the surrounding rocks.

Another striking vent has been dissected by the sea on the west side of Cemmaes Harbour. It appears to have been drilled through some of the thick limestone bands of the district. Large masses of vertical and crumpled limestone beds, as well as quartzite, have been caught up in the agglomerate, together with abundant blocks of grit, fragments of shale, and pieces of a pale felsite. Numerous narrow dolerite dykes traverse the neck, and where some of these have weathered and left straight clefts with vertical walls of agglomerate or limestone, they present at once a singularly picturesque coast-scenery and an impressive picture of the fissures of an ancient volcano.

There can be no doubt that these volcanic orifices, since they have broken through some of the limestones and quartzites of the Amlwch slates, are younger than the volcanic and other strata that lie to the south-west of them. But they may well have been the

vents from which some of the later tuffs were discharged; for beyond and above the limestones and black shales of Cemmaes, other volcanic breccias and ashes, with limestone, quartzite, conglomerate, and thin seams of black shale, continue to the extreme northern headlands. The amount of fine volcanic detritus distributed through these strata is very great. We can clearly make out that while ordinary sedimentation was in progress, an almost constant but variable discharge of fragmental materials took place from the vents in the neighbourhood. Sometimes a special paroxysm of explosion would give rise to a distinct band of breccia or of tuff, but even where, during a time of comparative quiescence, the ordinary sand or mud predominated, it was generally mingled with more or less volcanic dust.

Some bands of conglomerate in this group of strata deserve particular notice. The most conspicuous of these, seen at Porth Wen, is made up of quartz and quartzite blocks, imbedded in a reddish matrix largely composed of ashy material, and recalling the red spotted tuffs of Llyn Padarn. The occurrence of strong conglomerates near the top of a volcanic series has been noted at St. David's, Llyn Padarn, and Bangor. In none of these localities, as I have tried to show, do the conglomerates mark an unconformability or serious break between two widely separated groups of rock. The Anglesey section entirely supports this view, for the conglomerates are there merely intercalations in a continuous sequence of deposits; they are succeeded by tuffs and shales like those which underlie them. The interposition of such coarse materials, however, may undoubtedly indicate local disturbance, connected, perhaps, in this and the other localities, with terrestrial readjustments consequent upon the waning of volcanic energy.

The detailed geological structure of Anglesey is still far from being completely understood. There is reason to suspect that considerable plication, perhaps even inversion, of the strata has taken place, and that, by denudation, detached portions of some of the higher groups have been left in different parts of the island. The occurrence of Upper-Silurian fossils in several localities adds to the perplexity of the problem by indicating that, among the folds and hardly distinguishable from the older slates, portions of Upper-Silurian formations may have been caught and preserved. These difficulties, moreover, involve in some obscurity the closing phases of volcanic activity in Wales; for until they are to some extent, at least, removed, we shall be left in doubt whether the little vents of

the north coast of Anglesey, which were in eruption probably during Bala time, were the last of the long succession of Welsh volcanoes. If the black shales of Parys Mountain are really referable to the horizon of the Mayhill Sandstone, the two great igneous bands between which they lie would seem to mark an outbreak of volcanic energy during Upper-Silurian time. No other indications, however, of eruptions of that age having been met with in Great Britain, more careful investigation is required before such a position can be safely assigned to any rocks in Anglesey.

Putting these doubtful rocks aside for the present, we may, in conclusion, contrast the type of eruption in Anglesey with that of the great Snowdonian region. While the Caernarvonshire volcanoes were pouring forth their volumes of felsitic lava, and piling them up for thousands of feet on the sea-floor, the little northern Anglesey vents, not more than some five-and-twenty miles away, threw out only stones and dust, but continued their intermittent explosions until they had strewn the sea-bottom with detritus to a depth of many hundred feet.

There is yet another feature of interest in this independent group of submarine vents in Anglesey. Their operations appear to have begun before the earliest eruption of the Bala volcanoes in Caernarvonshire. Their first beginnings may, indeed, have been coeval with the explosions that produced the older Arenig tuffs of Merionethshire; their latest discharges were possibly the last manifestations of volcanic energy in Wales. They seem thus to bridge over the vast interval from Tremadoc to Upper-Bala, possibly even to Upper-Silurian time. But we may, perhaps, connect them with the still earlier period of Cambrian vulcanism. I have referred to the evidence which appears to show that the vents which gave forth the lavas and tuffs of Moel Trefan and Llyn Padarn gradually moved northwards, and continued in eruption until after the beginning of the deposition of the black slates that are generally regarded as Arenig. The Anglesey vents may thus be looked upon as evidence of a still further shifting of the active orifices northward. In this view, while the Aran and Cader-Idris volcanoes broke out in Tremadoc and continued through Arenig time, and the Snowdonian group was confined to Bala time, a line of vents opened to the north-west in the Cambrian period before the epoch of the Llanberis slates, and dying out in the south, continued to manifest a minor degree of energy, frequently discharging fragmental materials, but no lava, over the sea-bottom, until, towards the close of the Bala period, possibly even in Upper-Silurian time, they finally became extinct.

(*b*) Lake District.—(Arenig to close of Bala Period.)

From the time of the appearance of Sedgwick's classic letters to Wordsworth, no volcanic area of Britain has probably been so well known in a general sense to the ordinary travelling public as the district of the English Lakes. Many geologists have since then visited the ground, and not a few of them have published additions to our knowledge respecting what is now known as the Borrowdale Volcanic Series. The most elaborate and detailed account of any part of it is that given by the late Mr. J. C. Ward in the Geological-Survey Memoir, wherein he embodied the results of his minute investigation and mapping of the northern portion of the district *. Notices of the petrography of some of the more interesting rocks have subsequently been published by Mr. Rutley, Professor Bonney, and others. But up to the present time no complete memoir on the volcanic geology of the Lake District as a whole has appeared. The sheets of the Geological-Survey map present a graphic view of the general distribution of the rocks, but so rapid has the progress of certain branches of geology been since these sheets were published, that the map is even now susceptible of considerable improvement.

In estimating the area over which the volcanic rocks of the Lake District are spread, geologists are apt to consider only the tract which lies to the south of Keswick and stretches southward to a line drawn from the Duddon Sands to Shap. But it can easily be shown that this area falls far short of the extent of that wherein the rocks can still be traced, and yet further short of that over which the lavas and ashes originally spread. For, in the first place, the volcanic group can be followed round the eastern end of the mountain-group which culminates in Skiddaw, and along the northern base of these heights to Cockermouth, though only a narrow fringe of it emerges from underneath the Carboniferous series. It is thus manifest that the volcanic rocks once stretched completely across Skiddaw and its neighbours, and that they extend northwards below the Whitehaven Coal-field. But, in the next place, far beyond these limits, volcanic rocks, which there can be little doubt were originally continuous with those of the Lakes, emerge from beneath the base of the Cross-Fell escarpment, and still farther to the east a prolongation of the same group rises for a brief space to the surface

* Sheet 101 S.E. of the Geological Survey of England and Wales and Explanation illustrating the same; also papers by him in Quart. Journ. Geol. Soc. vols. xxxi., xxxii. (1875–76). See also Aveline and Hughes, Mem. Geol. Survey, Sheet 98 N.E. (Kendal, Sedbergh, &c.).

from under the great limestone sheets of Upper Teesdale. Between the north-western and south-eastern limits within which the rocks can now be seen there intervenes a distance of some eleven miles, while the extreme length of the tract from south-west to north-east is about fifty miles. Even if we take these figures as marking the approximate boundaries of the region covered by the volcanic ejections, it cannot be less than 550 square miles. But this is probably much less than the original area.

The thickness of the accumulated volcanic materials is proportionate to the large tract of country over which they have been spread. From various causes, it is difficult to arrive satisfactorily at any precise statement on this question. In a volcanic series bedding is apt to be obscure where, as in the present case, there are no interstratified bands of ordinary sedimentary strata to mark it off. It tends moreover to vary considerably and rapidly within short distances, not only from subsequent unequal movements of subsidence or elevation, but from the very conditions of original accumulation. Mr. Ward considered that the maximum thickness of the volcanic group of the Lake District might be taken to range from 12,000 to 15,000 feet*. Professors Harkness and Nicholson, on the other hand, gave the average thickness as not more than 5000 feet†. My own impression is that the truth is to be found somewhere between these two estimates, and that the maximum thickness probably does not exceed 8000 or 9000 feet. In any case there cannot, I think, be any doubt that we have here the thickest accumulation of volcanic material anywhere known to exist in Britain.

The geological age of this remarkable volcanic episode is fortunately fixed by definite palæontological horizons both below and above. The base of the volcanic group rests upon and is interstratified with the Skiddaw Slate‡, which from the evidence of its fossils is paralleled with the Arenig rocks of Wales. The highest members of the group are interstratified with the Coniston Limestone, which from its abundant fauna can without hesitation be placed on the same platform as the Bala Limestone of Wales, and is immediately followed by the Upper-Silurian series. Thus the volcanic history comprises the geological interval that elapsed between the later part of the Arenig period and the close of the Bala

* Ward, *op. cit.* p. 46. † Brit. Assoc. 1870, Sectional Reports, p. 74.

‡ Mr. Dakyns, however, believes that the volcanic group lies unconformably on the Skiddaw Slate (Geol. Mag. 1869, pp. 56, 116), and Prof. Nicholson has expressed the same opinion (*op. cit.* pp. 105, 167; Proc. Geol. Assoc. vol. iii. p. 106).

period. It begins probably not so far back as that of the Arenig group of Merionethshire, and its termination was perhaps coincident with the dying out of the Snowdonian volcanoes. But it contains no record of a great break or interval of quiescence like that which separated the Arenig from the Bala eruptions in Wales.

The materials that form this enormous volcanic pile consist entirely of lavas and ashes. No intercalations of ordinary sedimentary material have been met with in it, save at the bottom and at the top. The lower lavas, well seen among the hills to the south of Keswick, were shown by Mr. Ward to be intermediate between felsites and dolerites in regard to their silica percentage, and he proposed for them the name of felsi-dolerites. They are comprised in the group of the porphyrites or altered andesites. From the analyses published by Mr. Ward, the amount of silica appears to range up to about 60 per cent.* They are close-grained, dull dark-grey to black rocks, breaking, where fresh, with a splintery or conchoidal fracture, showing a few minute striated felspars, apt to weather with a pale-brown or yellowish-grey crust, and sometimes strongly vesicular or amygdaloidal. They present many external resemblances to some of the porphyrites of the Lower Old Red Sandstone of Scotland. A microscopic examination of specimens collected by Dr. Hatch and myself from the hills to the south of Keswick shows the rocks to be true andesites, composed of a multitude of slender laths (sometimes large porphyritic crystals) of felspar with a glassy brownish groundmass, and with some chloritic material probably representing augite, but with no trace of quartz †.

The andesitic lavas are more particularly developed in the lower and central part of the volcanic group. They rise into ranges of craggy hills above the Skiddaw Slates, and form, with their accompanying tuffs, the most rugged and lofty ground in the Lake District. They extend even to the southern margin of the volcanic area at one locality to the south-west of Coniston, where they may be seen with their characteristic vesicular structure forming a succession of distinct flows or beds, striking at the Coniston Limestone which lies upon them with a decided, though probably very local,

* Quart. Journ. Geol. Soc. vol. xxxi. (1875) p. 408, vol. xxxii. (1876) p. 24. Geology of Northern Part of Lake District (Mem. Geol. Survey), p. 22. In a subsequent series of analyses of the more basic lavas of Eycott Hill, the percentage of silica is given as from 51 to 53·3 and these rocks are compared with dolerites (Monthly Microscopical Journ. 1877, p. 246).

† These rocks were mapped as tuffs by Mr. Ward.

unconformability *. One of the flows from this locality proves under the microscope to be much more basic than the general type of these rocks. Dr. Hatch informs me that it approaches to a basalt, containing porphyritic crystals of fresh augite instead of the usual felspars, and showing a groundmass of felspar microliths with some granules of augite and dispersed magnetite. This local increase of basic composition is interesting as occurring towards the top of the volcanic group. A porphyritic and somewhat vesicular andesite with large crystals of striated felspar in a dark almost isotropic groundmass occurs under the Coniston Limestone near Stockdale.

Mr. Ward was much impressed with the widespread metamorphism which he believed all the volcanic rocks of this region had undergone, and as a consequence of which arose the difficulty he found in discriminating between close-grained lavas and fine tuffs. There is, of course, a general induration of the rocks, while cleavage has widely, and sometimes very seriously, affected them. There is also local metamorphism round such bosses as the Shap granite, but the evidence of any general and serious metamorphism of the whole area does not seem to me to be convincing.

With regard to the original structure and subsequent alteration of some of the andesitic lavas, an interesting section has recently been cut along the road up Borrowdale a little south of the Bowder Stone. Several bands of coarse amygdaloidal lava may there be seen interstratified among tuffs. The calcite amygdules in these rocks are arranged parallel to the bedding and therefore in the planes of flow, while those lined with chlorite are more usually deformed parallel to the direction of the cleavage. This difference suggests that before the cleavage took place the rocks had been traversed by probably meteoric water producing internal alteration and rearrangements, in virtue of which the vesicles along certain paths of permeation were filled up with calcite, so as then to offer some resistance to the cleavage, while those which remained empty or which had been merely lined with infiltrated substance were flattened and pulled out of shape.

Though acid lavas are not wholly absent from the central and

* This unconformability has been described and discussed by various observers. The general impression has been, I think, that the break is only of local importance. Mr. Aveline, however, believed it to be much more serious, and he regarded the volcanic rocks which were ejected during the deposition of the Coniston Limestone series as much later in date than those of the Borrowdale group. See Mem. Geol. Survey, Explanation to Sheet 98 N.E., 2nd edit. p. 8 (1888).

lower parts of the volcanic group, it is at the top that their chief development appears to occur. These rocks may be grouped together as felsites (rhyolites). Some of them have been described by Mr. Rutley, who has found them to exhibit beautiful perlitic and spherulitic structures *. That such rocks as these were poured out in a vitreous condition like obsidian or pitchstone cannot be doubted. They probably play a much larger part in the structure of the southern part at least of the volcanic area than the published maps would suggest, and a detailed survey and petrographical study of them would well reward the needful labour †. A fine series of felsites is interbedded in the lower part of the Coniston Limestone, and spreads out underneath it along the southern margin of the volcanic district from the Shap granite south-westward for some miles ‡. Between the valleys of the Sprint and Kent these felsites (which farther east are said to be 700 feet thick) may be seen interposed between the limestone and the fossiliferous calcareous shales below it, while from underneath the latter other sheets rise up into the range of hills behind. Occasionally a distinct nodular structure may be observed in the felsites, sometimes minute, like an oolite, in other parts presenting large rounded balls which have been more or less flattened and elongated in the direction of cleavage. Some portions of the rocks have been so intensely cleaved as to become a kind of fissile slate that might at first be mistaken for felsitic tuff. Short, extremely irregular, branching veins of a fine cherty felsitic substance, which occasionally shows a well-marked flow-structure parallel to the walls, traverse certain parts of the felsite.

The abundance and persistence of such thoroughly acid lavas along the southern edge of the volcanic area where the youngest outflows are found, is a fact of much interest and importance in the history of the eruptions of this region. It harmonizes with the observations made in Wales, where both in the Arenig and Bala groups a marked increase in acidity is noticeable in the later volcanic products. At the same time, as above mentioned, there is evidence also of the discharge of more basic materials towards the close of the eruptions, and even of the outflow of a lava approaching in character to basalt.

According to the Geological-Survey maps, by far the largest part

* 'The Felsitic Lavas of England and Wales,' Mem. Geol. Survey, 1885, pp. 12–15.

† Unfortunately these acid lavas are not distinguished from the others in the Geological-Survey maps.

‡ 'Geology of Kendal, &c.,' Mem. Geol. Survey, Sheet 98 N.E., 2nd ed. p. 9.

of the volcanic district consists of pyroclastic materials. When my lamented friend, the late Mr. Ward, was engaged in mapping the northern part of the district, which he did with so much enthusiasm, I had an opportunity of going over some of the ground with him, and of learning from him his ideas as to the nature and distribution of the rocks and the general structure of the region. I remember the difficulty I had in recognizing as tuff much of what he had mapped as such, and I felt that had I been myself required, without his experience of the ground, to map the rocks, I should probably have greatly enlarged the area coloured as lava, with a corresponding reduction of that coloured as tuff. A recent visit to the district has revived these doubts. It is quite true, as Mr. Ward maintains, that where the finer-grained tuffs have undergone some degree of metamorphism, they can hardly, by any test in the field, be distinguished from compact lavas. He was himself quite aware of the objections that might be made to his mapping *, but the conclusions he reached had been deduced only after years of unremitting study in the field and with the microscope and in the light of experience gained in other volcanic regions. Nevertheless I think that he has somewhat exaggerated the amount of fragmental material in the northern part of the Lake District, and that the mapping, so consistently and ably carried out by him and followed by those members of the Survey who mapped the rest of the ground, led to similar overrepresentation there. Some portions of the so-called tuffs of the Keswick region are undoubtedly andesites; other parts in the southern tracts include intercalated bands of felsite as well as andesite.

But even with this limitation, the pyroclastic material in the Lake District is undoubtedly very great in amount. It varies in texture from coarse breccia or agglomerate, with blocks measuring several yards across, to the most impalpable compacted volcanic dust. In the lower parts of the group some of the tuffs abound in blocks and chips of Skiddaw Slate. Some good examples of this kind may be seen in Borrowdale, below Falcon Crag and at the Quayfoot quarries. Where the tuff is largely made up of fragments of dark blue slate, it much resembles the slate-tuffs of Cader Idris.

* He says :—'I snall be very much surprised if my mapping of many parts of the district be not severely criticised and found fault with by those who examine only one small area and do not take into consideration all the facts gathered together, during the course of several years, from every mountain flank and summit.' *Op. cit.* p. 25.

Some of the pieces of slate are six or eight inches long and are now placed parallel to the cleavage of the rock. Among the slate débris, however, felspar crystals and felsitic fragments may be observed. Bands of coarser and finer green tuff show very clearly the bedding in spite of the marked cleavage.

But throughout the whole volcanic group the material of the tuff is chiefly of thoroughly volcanic origin, and its distribution appears to agree on the whole with that of the bedded lavas. In the older portions of the group it is probably mainly derived from andesitic rocks, though perhaps with an occasional intermingling of felsitic detritus, while in the higher parts many of the tuffs are markedly felsitic. Some of the ejected ash must have been an exceedingly fine dust. Compacted layers of such material form bands of green slates, which may occasionally be seen to consist of alternations of coarser and finer detritus, now and then false-bedded. Such tuffs bring vividly before the mind the intermittent explosions, varying a little in intensity, by which so much of the fabric of the Lake mountains was built up. Breccias of varying coarseness are likewise abundant, composed of fragments of andesite and older tuffs in the central and lower parts of the volcanic group, and mainly of felsitic detritus in the upper parts. Some of these rocks, wherein the blocks measure several yards across, are probably not far from the eruptive vents, as at Sourmilk Gill and below Honister Pass. Generally the stones are angular, but occasionally more or less rounded. Stratification can generally be detected among these fragmental rocks, but it is apt to be concealed or effaced by the cleavage, while it is further obscured by that widespread induration on which Mr. Ward has laid so much stress.

Little has yet been done in identifying any of the vents from which the vast mass of the volcanic material of the Lake District was ejected. Mr. Ward believed that the diabase boss forming the Castle Head of Keswick marks the site of " one of the main volcanic centres of this particular district " *, whence the great lava-sheets to the southward flowed out. There are obviously two groups of bosses on the northern side of the district, and both of these, in my opinion, may mark the position of vents. Some of them are occupied by more basic, others by more acid rocks. It is not necessary to suppose that the andesitic lavas ascended only from the former and the felsites from the latter. While the felsites on the whole are younger than the more basic lavas, they may have been erupted

* *Op. cit.* p. 70.

from vents which had previously emitted andesites, so that the present plug may represent only the later and more acid protrusions. Of the more basic bosses, besides the Castle Head, there is the large mass forming Carrock Fell, wherein two distinct protrusions may be recognized, each of which may mark the position of a volcanic orifice. One of them is occupied with a thoroughly typical granophyre, the other with an augite-mica-diorite, and they rise abruptly out of the Skiddaw Slate. Their position within the great volcanic ring round Skiddaw is such as would have been occupied by important vents.

There is a considerable number of bosses formed of more acid rocks, some at least of which not improbably indicate the site of volcanic vents; two of these form conspicuous features on either side of the Vale of St. John; they consist of microgranite, and rise like great plugs through the Skiddaw Slates, as well as through the base of the volcanic group. The view of the more eastern hill, as seen from the west, is at once suggestive of a "neck." These masses measure roughly about a square mile each. With the acid intrusions may possibly be associated some of the other masses of granophyre and microgranite which have long attracted attention in this region. But there is also evidence of the protrusion of portions of an acid and basic magma at a time long subsequent to the eruption of the volcanic group of Borrowdale. The Shap granite, for example, is one of these younger bosses; it invaded the area after the deposition and uptilting of the Upper-Silurian strata, but before the beginning of the Carboniferous period, for the lowest members of the Carboniferous series are full of detritus derived from its waste.

But it is not merely in large bosses of massive rocks, whether diabases, gabbros, felsites, granophyres, or granites, that we have to seek the vents which supplied the lavas and tuffs of the Lake District. We cannot make out such a decided accumulation of the volcanic materials in certain directions as to indicate the quarters where the centres of eruption should be sought. On the contrary, the confused commingling of materials, and the comparative shortness of the outcrop of the several sheets which have been traced, suggest that there was no one great central volcano, but more probably many scattered vents, which threw out their lavas and ashes over no very wide area, but which stood near enough to each other to allow their ejected materials to meet and mingle. The scene seems to have been rather of the type

of the Phlegræan fields than of Etna and Vesuvius. If this surmise be true, we may expect yet to recognize many little necks scattered over the volcanic district and marking the positions of some of these vanished cones.

One of them, which has not before been noticed, may, I think, be shown to have stood near Grange at the mouth of Borrowdale. In the little Comb Beck, the Skiddaw Slates are pierced by a mass of extremely coarse agglomerate, forming a rudely circular boss. The slates are greatly disturbed along the edges of the boss, so much so, indeed, that it is in some places difficult to draw a line between them and the material of the agglomerate. That material is made up of angular blocks, varying in size up to three feet long, stuck in every position and angle in an intensely indurated matrix formed apparently of comminuted débris like the stones. The blocks consist of a finely stratified shale, which is now hardened into a kind of hornstone, with small felsitic fragments. I could see no slags or bombs of any kind. There is no trace of cleavage among the blocks, nor is the matrix itself sensibly cleaved. That this is a small volcanic neck cannot, I think, admit of doubt. It has been blown through the Skiddaw Slates, and is now filled up with the débris of these slates. Its formation took place before the cleavage of the strata, and its firm position and great induration enabled it to resist the cleavage which has so powerfully affected the slates and many members of the volcanic group.

It was the opinion of my predecessor, Sir Andrew Ramsay, and likewise of Mr. Ward, that the Cumbrian volcanic action was mainly subaerial. This opinion was founded chiefly on the fact that, save at the bottom and top of the series, there is no evidence of any interstratified sediment of non-volcanic kind. The absence of such interstratification may undoubtedly furnish a presumption in favour of this view, but, of course, it is by no means a proof. We might conceive that the eruptions followed each other so continuously on the sea-floor and at so great a distance from land that no deposition of sand or mud from the outside could sensibly affect the accumulation of volcanic material. I confess that the well-defined stratification of many of the fine tuffs is rather suggestive to my mind of submarine than of subaerial accumulation. At the same time, there seems no reason why, here and there at least, the volcanic cones should not have risen above the water, though their materials would be washed down and spread out by the waves. It is worthy of remark that in the exposures of the Borrowdale

volcanic series far to the east, under Cross Fell, the volcanic tuffs are intercalated among sedimentary strata like the Skiddaw Slates, and containing the same fossils. Here, at the outer confines of the volcanic district, the ejected materials evidently fell on the sea-floor and mingled there with ordinary sediment *.

One of the most marked points of contrast between the Cumbrian and the Welsh volcanic districts is to be found in the great paucity of sills in the former region. A few sheets of diorite and diabase have been mapped, especially in the lower parts of the volcanic group and in the underlying Skiddaw Slates. On the other hand, dykes are in some parts of the district not unfrequent, and certainly play a much more prominent part here than they do in the Welsh volcanic districts. The majority of them consist of felsites, quartz-porphyries, diorites, and mica-traps. But there is reason to suspect that where they are crowded together near the granite, as around Shap Fells, they ought to be connected with the uprise of the post-Silurian granitic magma rather than with the history of the volcanic group. If this series of dykes be eliminated, there remain comparatively few that can with any confidence be associated with the eruption of the Borrowdale rocks.

### (*c*) Scotland.—Llandeilo Period.

It has been generally supposed that the Silurian rocks of Scotland contain no contemporaneously erupted volcanic rocks. They have been long known, indeed, to include many protrusions of igneous material of various kinds, but these have been looked upon as intrusive dykes and bosses, much younger than the strata among which they are found. The recent work of the Geological Survey, however, and more especially the numerous and careful traverses of my friend and colleague Mr. Peach, have revealed the unlooked-for and important fact that a large number of these supposed dykes are really portions of a volcanic group brought up on the crests of anticlinal folds and laid bare by denudation. This group can be traced for at least a hundred miles from north-east to south-west over a belt of country sometimes thirty miles broad. Its original limits cannot be ascertained, but they obviously exceeded those within which the rocks can now be seen. Nevertheless the present boundaries embrace an area of nearly 2000 square miles. This Palæozoic volcanic region is thus one of the most extensive in the British

* See J. G. Goodchild in H. B. Woodward's 'Geology of England and Wales,' p. 81.

Isles. Owing, however, to the constant plication of the strata, and the wide space which the overlying sedimentary deposits are thus made to cover, the volcanic group only comes occasionally into view and thus occupies but a mere fraction of the superficial extent of the region over which its scattered outcrops appear. These exposures, sometimes only a few square yards in extent, may always be looked for where the anticlinal folds bring up a sufficiently low portion of the Silurian series; they prove that a vast volcanic floor underlies the visible Lower-Silurian grits and shales over the length and breadth of the southern uplands of Scotland.

In the early days of the application of the microscope to the elucidation of questions in field-geology I found some of the Lower-Silurian shales of Moffatdale to contain fresh felspar crystals, which I felt tolerably certain had been supplied by volcanic explosions; and I used to speculate on the possibility of their having been wind-borne from the volcanoes of the Lake District. I had at that time no suspicion that their source was rather to be sought under my feet. The presence of volcanic rocks underneath the uplands of the south of Scotland may help to explain the frequent felspathic composition of many of the Silurian greywackes and shales of that region, and particularly the abundance of andesitic and felsitic fragments in them.

Without anticipating the details which will properly appear in the Memoirs of the Survey, I may briefly indicate the visible boundaries of the volcanic group and refer to some of the localities where it may best be seen. The most easterly points where it has been recognized by Mr. Peach stand on the crests of some sharp anticlinal folds near St. Mary's Loch and near Leadburn in Peebles-shire. Farther westwards it appears at many places along the northern border of the Silurian territory, as at Romanno Bridge, Kilbucho, Culter Water, and Abington, the length and breadth of the exposure depending partly on the breadth of the anticline and partly on the depth to which it has been cut down by denudation. Near Sanquhar it opens out for a breadth of more than a mile, and is seen at intervals across the wild moorlands of Carrick, until from the Stinchar valley it widens out seaward and occupies most of the coast-line of Ayrshire between Girvan and the mouth of Loch Ryan. It probably rises again along a fold near Port Patrick, and it is seen at various points along the southern borders of the Silurian uplands, as near Castle Douglas, at Glenkiln, Bell Craig near Moffat, and the head of Ettrickdale.

The best sections are those exposed along the coast to the north and south of Ballantrae. When that ground was first examined by the Geological Survey the hypothetical views in regard to metamorphism already referred to were in full ascendant, and the rocks were mapped on the same general principles as those which had been followed in Wales. Professor Bonney, however, a few years later recognized the true igneous nature of many of the rocks. He found that there were porphyrite lavas and agglomerates which he regarded as of Old Red Sandstone age, likewise intrusive serpentines and gabbros *.

The volcanic materials have not yet been systematically studied. I may say, however, that they include amygdaloidal lavas of the "porphyrite" type, diabases, agglomerates made up of blocks of these lavas, and tuffs, chiefly basic, but including some that are probably felsitic. In Ayrshire massive sheets of amygdaloidal and porphyritic lavas occur which singularly resemble the porphyrites of the Old Red Sandstone of the same country. Similar rocks appear where the volcanic group is brought to the surface all along the northern part of the Silurian ground; some of them are markedly slaggy, even with a ropy surface, while the fragmental beds associated with them sometimes consist of blocks of similar slag.

Along the south-eastern parts of the volcanic area the ejected materials have a more acid character. They consist largely of fine tuffs (probably in great measure felsitic), which towards the north-east are gradually interleaved with ordinary sediment till the ashy character disappears. But, as I have already remarked, there is reason to believe that the overlying greywackes and shales derived part of their material either directly from volcanic explosions or from the attrition of banks of lavas and tuffs exposed to denudation.

The dying out of the volcanic material towards the north-east probably indicates that the vents of the period lay rather in the central or south-western parts of the district. Unfortunately, the limited extent of the exposures of the rocks makes it a hopeless task to search for traces of these vents over by far the largest part of the area. There are two localities, however, where the search may be made with better prospect of success. One of these is a tract to the north of Sanquhar in Nithsdale. Besides the porphyrites, which resemble some of the Ayrshire rocks, there occur numerous varieties of tuff, which Dr. Hatch has found to present under the microscope many points of interest. Some of them are com-

* Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 769.

posed mainly of fragments of microlithic rocks, perhaps andesites, with detached crystals of felspars. Others present, not only felspars, but large well-formed crystals of augite similar to those of modern volcanic tuffs. There are likewise bosses of gabbro and other intrusive rocks. A more thorough examination of this tract will doubtless throw much light on the history of this volcanic episode.

The other part of the region where relics of some of the eruptive vents may exist is the district south of Girvan. Various bosses and sheets of eruptive rock rise there through the lavas and agglomerates, some of which may mark the sites of volcanic orifices. The sheets of gabbro and serpentine running in a north-east and south-west direction with the general strike of the rocks remind us of the later basic sills of the Welsh volcanic districts. But this ground will be revised in the light of recent researches, and more definite information will doubtless then be obtained regarding its structure.

The geological horizon of this extensive volcanic group in the Lower-Silurian series of the south of Scotland can be fixed with precision. On the coast of Ayrshire, at Bennane Head, near Ballantrae, Professor Lapworth found in some hardened black shales a group of graptolites which indicate an unmistakable Arenig horizon*. These fossils lie below the volcanic group, which is thus not older than the Arenig period. The upper limit is admirably defined in many sections in the eastern part of the area, by the superposition of the Glenkiln black shales upon it. These shales are distinguished by an assemblage of Llandeilo graptolites. The volcanic eruptions are thus shown to have occurred within the Llandeilo period. But they do not appear to have entirely ceased till after the close of that period, for in at least one locality, that of Hartfell, a moderately coarse volcanic agglomerate occurs in the heart of the so-called "barren mudstones" of the Hartfell black-shale group which, from its graptolites, is placed on the horizon of the Bala rocks.

Some interesting facts have likewise been observed by Mr. Peach and his colleagues regarding the usual upward limit of the volcanic group. Between the Glenkiln black shales and the volcanic sheets below them alternations of green, grey, or red shaly mudstones and flinty greywackes are interleaved with fine tuffs, and are specially marked by the occurrence in them of nodules and bands of black and reddish chert. This latter substance, on being submitted to Dr. Hinde, was found by him to yield twenty-three new species of Radiolaria belonging to twelve genera, of which half are new. It

* Geol. Mag. 1889, p. 22.

thus appears that when the main volcanic activity came to a close it was succeeded by a time of such quiescence, and such slow, tranquil sedimentation in clear, perhaps moderately deep water, that a true Radiolarian ooze gathered over the sea-bottom *.

### (*d*) Ireland.—Llandeilo, Bala, Upper-Silurian Periods.

Into the east of Ireland the Lower-Silurian rocks are prolonged from Scotland, from the Lake District, and from Wales. Though greatly concealed under younger formations across the breadth of the island, and occasionally interrupted by the uprise of still older masses than themselves, they nevertheless occupy by much the larger part of the maritime counties from Belfast Lough to the southern coast-line of Waterford, even as far as Dungarvan Harbour. With the same lithological types of sedimentary deposits as in other parts of the United Kingdom, they carry with them here also their characteristic records of contemporaneous volcanic action. Though nowhere piled into such magnificent mountain-masses as in Westmoreland and North Wales, they are traceable over a wider area than in any other region of Britain.

Much remains to be done, both in the field and in the laboratory and microscope-room, before our knowledge of the vulcanism of Lower-Silurian time in Ireland is brought abreast of our acquaintance with that of other portions of the United Kingdom. In especial, the several geological horizons of the rocks have only been approximately fixed. Great difficulty was experienced by the Geological Survey in drawing any satisfactory line between Llandeilo and Bala rocks. This arose not so much from deficiency of fossil evidence as from the way in which the fossils of each group seemed to occur in alternating bands in what might be regarded as a continuous series of strata. Indeed, in some localities it almost appeared as if the occurrence of one or other *facies* of fossils depended mainly on lithological characters indicative of original conditions of deposit, for the Llandeilo forms recurred where black shales set in, while Bala forms made their reappearance where calcareous and gritty strata predominated †. It remains to be seen how far there is any foundation in actual fact for this impression. More recent work in Scotland rather suggests that the parallel repetition

* Ann. Mag. Nat. Hist. (1890) 6th ser. vi. p. 40.

† Jukes was disposed to regard the two faunas as essentially coeval, but inhabiting different kinds of sea-bottom. See his note, Explanation of Sheets 167, 168, 178, 179, p. 30.

of the two types is due to rapid and constant plication, whereby the two groups of rock, neither of them of great thickness, have been folded with each other in such a way that without the evidence of an established sequence of fossils, or the aid of continuous sections, it becomes extremely difficult to make out the stratigraphical order in any district. When the ground is attacked anew in detail with the assistance of such palæontological and lithological horizons as have permitted the complicated structure of the southern uplands of Scotland to be unravelled, we may be enabled to tabulate the successive phases of the volcanic history of the region in a way which is for the present impossible. We have no palæontological evidence of any Arenig rocks in the east of Ireland, nor of the top of the Bala series. The volcanic history of the region is thus unmistakably comprised within the later half of Lower-Silurian time, between the beginning of the Llandeilo and the close of the Bala period. I must therefore, in the meantime, content myself with this general limit of geological chronology, and make no attempt to trace the relative antiquity of the igneous rocks in the several districts in which they are distributed.

Viewing the volcanic region of eastern Ireland as a whole, we are first struck by the feebleness of the manifestations of eruptivity in the north and their increasing development as we trace them southwards. At the northern end of the Silurian area in County Down, thin bands of "felstone" and "ash" have been recognized by the Survey, interstratified with the highly-inclined and plicated Silurian rocks. As the latter are plainly a continuation of the strata which have been mapped out zone by zone in the south of Scotland, the volcanic intercalations may possibly lie in the same general plaform which is there so well marked *. Far in the interior, some 70 or 80 miles to the south-west, a strongly-marked horizon of tuffs, breccias, and coarse agglomerates runs through the counties of Monaghan and Cavan †. Farther south a more important volcanic centre lies on the borders of Louth and Meath, where a group of lavas and tuffs may be followed for a distance of about twelve miles ‡. Unfortunately, large tracts of Carboniferous strata now conceal the Lower-Silurian rocks; but where the latter rise to the surface between Drogheda and Balbriggan, several groups of felstone-sheets and tuffs are observable, indicative probably of some minor vents

* See Sheet 49, Geol. Survey Ireland, and Explanation thereto.

† *Ibid.* Sheet 69, and Explanation of Sheets 68 & 69, pp. 9, 13, 15.

‡ *Ibid.* Sheets 81 & 91, and Explanation.

along the borders of the counties of Meath and Dublin *. The alternation of lavas and tuffs is here well displayed, some of the volcanic breccias being coarse accumulations in which pieces of shale derived from some older part of the Palæozoic formations are abundant.

Crossing over the broad belt of Carboniferous Limestone through which the Liffey flows into Dublin Bay, we come to the great continuous tract of older Palæozoic rocks which stretches southward to the cliffs of Waterford. Through this tract runs the huge ridge of the Wicklow and Carlow granite. On the west side of this intrusive mass bands of "greenstone-ash," as well as "felspathic ashes," have been traced among the Silurian rocks by the Geological Survey. But it is on the south-east side of the granite that the volcanic intercalations are best displayed. Indeed, from Wicklow Head to Dungarvan Harbour there is an almost continuous development of igneous rocks, rising into rocky eminences, trenched into ravines by the numerous streams, and laid bare by the waves in fine coast-cliffs. It is in this south-eastern part of Ireland, comprising the counties of Wicklow, Wexford, and Waterford, that the Lower-Silurian igneous rocks can best be studied. I shall accordingly ask your attention specially to the rocks there displayed, and the records they furnish regarding the history of volcanic action.

There are obviously various distinct centres of eruption in this long belt of country. The Rathdrum and Castletimon tract forms one of these. Another of less size culminates in Kilpatrick Hill, a few miles to the southward. Arklow Head marks the position of a third. The lavas and tuffs which set in a few miles to the south of that promontory, and may be said to extend without interruption to the south coast, were probably thrown out by a series of vents which, placed along a north-east and south-west line, united their ejections into one long submarine volcanic bank. There can be no doubt that the most active vents lay at the southern end of the belt, for there the volcanic materials are piled up in thickest mass, and succeed each other with comparatively trifling intercalations of ordinary sedimentary material. Some of these vents, as I shall relate in the sequel, have been cut open by the sea along a range of precipitous cliffs.

The comparatively feeble character of the volcanic energy during Lower-Silurian time in the south-east of Ireland is shown by the great contrast between the thickness of the volcanic intercalations

* *Ibid.* Sheets 91 & 92, and Explanation.

there and in Wales and the Lake country, but still more strikingly by innumerable sections where thin interstratifications of fine tuff or volcanic breccia occur among the ordinary sedimentary strata, and are sometimes crowded with Bala fossils. Some interesting illustrations of this feature are to be seen in the Enniscorthy district, where layers of fine felsitic tuff, sometimes less than an inch in thickness, lie among the shales. In some of the tuffs the lapilli are fragments of trachytic or andesitic rocks.

The most striking example of pyroclastic material I have met with is situated far to the south in County Waterford, close to Dunhill Bridge, where a remarkable group of fine volcanic breccias and grits occurs. These strata consist of coarser and finer detritus, enclosing angular fragments of felsites and grey and black shale. The felsites vary in texture, some of them presenting beautiful flow-structure. The stones are stuck at random through each bed, the largest being often at the bottom. The beds of breccia vary from a few inches to a foot or more in thickness. There can, I think, be little doubt that each of these breccia-bands points to a single volcanic explosion, whereby felsitic fragments were thrown out mingled with pieces of the Silurian strata, through which the vents were drilled. In a vertical thickness of some fifty feet of rock there must thus be a record of ten or twelve such explosions.

Nearer the active vents the fragmental deposits become, as usual, coarser and thicker. But I have not yet met with any thick masses of tuff like those of North Wales. So far as my examination has gone the tuffs are mainly felsitic. The so-called "greenstone-ash" of the Survey maps is certainly in many cases not a true tuff. This term was proposed by Jukes for certain apple-green to olive-brown flaky fissile rocks only found "in association with masses of greenstone." * Some years ago I had occasion to make a series of traverses in Wicklow and Wexford, and then convinced myself that in that part of the country the "greenstone-ashes" were probably crushed bands of the basic sills. Dr. Hatch has proved this to be their origin from a series of microscopic slides prepared from specimens collected by himself on the ground †. In other cases the "greenstone-ashes" seem to be excessively-cleaved or sheared felsites which have acquired a soapy feel and a dull green colour; but they also do include true tuffs. Thus, in one instance, at Ballyvoyle cross-roads, in the south of County Waterford, a "greenstone-

* Explanation of Sheets 129, 130, p. 13 (1869).

† Explanation of Sheets 138, 139

ash" is a dull green tuff full of fragments of felspar (chiefly plagioclase) and pieces of dark andesitic lavas. Another example may be found to the west of the Metal Man, near Tramore, where the tuff is full of fragments of felspar and shale cemented in a greenish-yellow material which may be palagonite.

The felsites of the south-east of Ireland form by much the largest proportion of the whole volcanic series. They occur as lenticular sheets from a few feet to several hundred feet in thickness, and occasionally traceable for some miles. On the whole, they are compact dull grey rocks, weathering with a white crust. A geologist familiar with the contemporary lavas of North Wales cannot fail to be struck with the absence of the coarse flow-structure so often characteristic of the felsites in that region. This structure, indeed, is not entirely absent from the Irish rocks, but it occurs, so far, at least, as I have seen, rather as a fine streakiness than in the bold lenticular bands so common in Caernarvonshire. In like manner the nodular structure, though not entirely absent, is rare *.

Until these felsites have been subjected to more detailed investigation, little can be said as to their petrography, and as to the points of resemblance or difference between them and those of other Lower-Silurian districts in the United Kingdom. An important step, however, in this direction has been taken by Dr. Hatch, who three years ago studied them on the ground, in the laboratory, and with the microscope. He found that some of them were soda-felsites or keratophyres (with albite as their felspar), that others were potash-felsites (with orthoclase as their felspar), while a third group contained both soda and potash, the last-named greatly preponderating †. The existence of soda-felsites had not been previously detected among British volcanic rocks, and it remains to be seen how far they may occur in the large and somewhat varied group of rocks combined under the general term "felsites." Dr. Hatch believes that these rocks probably graduate into the normal or orthoclase felsites; but it has not yet been possible to test this view on the ground, nor to ascertain whether there is any essential difference between the mode of occurrence of the two types.

I have said that the chief theatre of eruption lay towards the

* In Waterford nodular felsites occur with concretions varying from the size of a pea to several inches in diameter. Explanation to Sheets 167, 168, 178, and 179, p. 11.

† Explanation of Sheets 138, 139, p. 49, and Geol. Mag. 1889, p. 545.

south-west end of the volcanic belt. The coast-line of County Waterford, from Tramore westward to Ballyvoyle Head—a distance of nearly fifteen miles—presents, perhaps, the most wonderful series of sections of volcanic vents within the British Islands. No one coming from the inland is prepared for either the striking character of the cliff scenery or the extraordinary geological structure there presented, for the country is, on the whole, rather featureless, and much of it is smoothed over and obscured by a covering of drift, through which occasional knobs of the harder felsites protrude. The cliffs for mile after mile range from 100 to 150 or 200 feet in height, and present naked vertical walls of rock, trenched by occasional gullies, through which a descent may be made to the beach. Throughout the whole distance agglomerates and felsites succeed each other in bewildering confusion, varied here and there by the intercalation of Lower-Silurian shales and limestones involved and pierced by the igneous rocks. Hardly any bedded volcanic material is to be seen from one end to the other. The sea has laid bare a succession of volcanic vents placed so close to each other that it is difficult or impossible to separate them out. A careful study and detailed mapping of this marvellous coast-section is a task well worthy of the labour of any one desirous of making himself acquainted with some of the conditions of vulcanism during older Palæozoic time.

At the east end of the section, black shales containing Llandeilo graptolites, and calcareous bands full of Bala fossils, dip westward below a group of soda-felsites and felsitic tuffs, which seem to lie quite conformably on these strata. Here, then, we start with proof that the volcanic eruptions of this locality began during some part of the Bala period. But immediately to the west these bedded igneous rocks are broken through by a neck of coarse agglomerate stuck full of chips and blocks of shale, some of them a foot long, with abundant fragments of scoriform and flinty felsites. Some columnar dykes of dolerite cut through the neck, and a larger intrusion seems to have risen up the same funnel. The bedded tuffs appear again for a short distance, but they are soon replaced by a tumultuous mass of agglomerates. And from this part of the coast onwards for some distance all is disorder.

The agglomerates are crowded with blocks of various felsites and microgranites sometimes 18 inches in diameter, many of them presenting the most exquisite streaky flow-structure. The angularity of these stones and the abrupt truncation of their lines

of flow prove that they were derived from the shattering of already consolidated rocks. In other places the ejected materials consist almost wholly of black shale fragments, but with an intermixture of felsite-lapilli.

It is difficult to convey an adequate idea of the way in which the agglomerates are traversed by dykes, veins, and bosses of various felsites, and of how these break in endless confusion through each other. Some of these intrusive rocks are compact and amorphous, others are vesicular, others close-grained and columnar. Again and again they present the most perfect flow-structure, and it is noticeable that the lines of flow follow the inequalities of the walls of the fissure up which the rock has ascended, and not only so, but even of the surfaces of detached blocks of shale or felsite which have been caught up and enclosed in the still moving mass.

A few of these intrusive rocks have been examined in thin slices by Dr. Hatch. Most of them appear to be soda-felsites, but they include also rather decomposed rocks, some of which are probably diorites and quartz-diorites. Occasionally, thoroughly basic dykes (dolerite) may be observed.

In the midst of this tumultuous assemblage of volcanic masses, representing the roots of a group of ancient vents, there occur occasional interspaces occupied by ordinary stratified rocks. In the eastern part of the section these consist mainly of black shale, sometimes with calcareous bands, from which a series of Bala fossils has been obtained *. A very cursory examination suffices to show that these intercalations do not mark pauses in the volcanic eruptions. They are, in fact, portions of the marine accumulations under the sea-floor through which the vents were blown; they have been tossed about, crushed, and invaded by dykes and veins of felsite.

But certain other intercalated strips of stratified rocks present a special interest, for they bring before us examples of volcanic ashes that gathered on the sea-floor, but which were disrupted by later explosions. Thus, at the Knockmahon headland, well-bedded felspathic grits and ashy shales occur, thrown in among the general mass of eruptive material. As I have already remarked, it is difficult or impossible to fix the horizons of the stratified patches that are involved among the igneous ejections of this coast-section, save where they contain recognizable fossils, but the intercalation

* But see the Geol. Survey Memoir on Sheets 167, 168, 178, and 179, Ireland (1865), p. 28, for a description of the association of Bala and Llandeilo fossils on that coast-line.

of true bedded tuffs among them is a proof that volcanic action had been in operation there long before the outbreak of the vents which are now laid bare along the cliffs.

In the south-east of Ireland there is the usual association of acid and basic sills with the evidence of a superficial outpouring of lavas and ashes. But these intrusive masses play a much less imposing part than in Wales. They may be regarded, indeed, as bearing somewhat the same proportion to the comparatively feeble display of extrusive rocks in this region that the abundant and massive sheets of Merionethshire and Caernarvonshire do to the enormous piles of lavas and tuffs which overlie them.

Among the acid intrusive sheets the most conspicuous are those mapped by the Survey as "elvans." These rocks, as they occur in Wicklow and Wexford, have been examined by Dr. Hatch, who finds them to be micrographitic in structure, occasionally exhibiting micropegmatitic or granophyric modifications *. The true stratigraphical relations of these rocks have not yet been adequately investigated. Those of them which occur on the flanks of the great granite ridge are not improbably connected with that mass.

The basic sills, or "greenstones," consist largely of diabase, frequently altered into epidiorite; they include also varieties of diorite †. That they were intruded before the plication and cleavage of the rocks among which they lie is well shown by their crushed and sheared margins where they are in thick mass, and by their cleaved and almost schistose condition where they are thinner. The intense compression and crushing to which they have been subjected are well shown by the state of their component minerals, and notably by the paramorphism of the original augite into hornblende.

The scarcity of dykes associated with Silurian volcanic action is as noticeable in the south-east of Ireland as it is in Wales. I have observed a considerable number, indeed, but they are confined to the line of old vents on the Waterford coast, and, but for the clear cliff-sections cut by the sea, they would certainly have escaped observation, for they make no feature on the ground in the interior. They are sometimes distinctly columnar, and vary from less than a foot to many yards in width. They traverse both the agglomerates and the intrusive felsites. Most of them are of felsite, sometimes cellular; but in some cases they are dolerites. There is obviously no clue to the relative dates of these dykes.

* Explanation of Sheets 138 and 139, p. 53. † Hatch, *op. cit.* p. 49.

That some at least of the vents along the south coast of County Waterford may be vastly younger than the Lower-Silurian rocks through which they have forced their way is suggested, if not proved, by a section which is in some respects the most extraordinary of the whole of this remarkable series. The occurrence of a group of red strata was carefully noted by the late Mr. Du Noyer at Ballydouane Bay, when he was engaged in carrying on the Geological Survey of that part of the country. At first he regarded them as belonging to the Old Red Sandstone, which comes on in great force only a few miles to the west; but he subsequently arrived at the belief that they are really an integral part of the Lower-Silurian rocks of the district. Professor Jukes expressed himself in favour of this latter idea, which was thought to receive support from the occurrence of some reddish strata in the Lower-Silurian rocks of Tagoat, County Wexford *.

The occurrence of red rocks among Silurian strata, which are not usually red, might quite reasonably be looked for in the neighbourhood of Old Red Sandstone, Permian, or Triassic deposits. If these deposits once spread over the Silurian formations, a more or less decided "raddling" of the latter may have taken place. But in the present instance, though the Old Red Sandstone begins not many miles to the west, no such explanation of the colour of the strata is possible. The cliffs of Ballydouane Bay consist of red sandstone, red sandy shale, and conglomerate. The red tint is of that dull chocolate tone so characteristic of the Lower Old Red Sandstone. The conglomerates are immense accumulations of ancient shingle, consisting largely of pieces of white vein-quartz and quartzite, sometimes a foot long and often well water-worn. Some of the sandy beds are full of large scales of white mica, as if derived from some granitic or schistose region at no great distance. Taken as a whole, the strata are much less indurated and broken than the Silurian grits and shales of the district; some of them, indeed, weather into mere incoherent sand that crumbles under the fingers. There does not appear to be any positive proof that the red rocks are truly bedded with the ordinary Silurian strata, the junctions being faulted or obscured by intrusive igneous masses.

Nowhere in the British Islands, so far as I am aware, is there a similar group of strata among the Lower-Silurian rocks. If they belong to so ancient a series, they show that in the south of Ireland, during Lower-Silurian time, there arose a set of peculiar physical

* Explanation of Sheets 167, 168, 178, and 179 of the Geological Survey of Ireland (1865), p. 10.

conditions precisely like those that determined the accumulation of the Old Red Sandstone in the same region at a later geological period. And in that case, it is hardly possible to conceive that these conditions could have been confined to the extreme south of Ireland. We should certainly expect to meet with evidence of them elsewhere, at least in the same Silurian region.

While I hesitate to express a decided opinion in opposition to the conclusions of such experienced observers as Jukes and Du Noyer, I incline to believe that the rocks in question really belong to the Old Red Sandstone. If such shall finally be determined to be their geological position, they will supply evidence that some at least of the volcanic vents of the coast-line cannot be older than the Old Red Sandstone. They are pierced by masses of soda-felsite and by a coarse red agglomerate containing abundant pieces of felsite. These volcanic rocks belong to the same type as those which break through the undoubted Silurian rocks on either side. They may thus come to prove a recrudescence of volcanic energy in this same district at a much later geological period; and a new problem will arise to task the skill of the most accomplished field-geologist and petrographer—to unravel the structure and history of this chain of volcanic vents, and, in so doing, to detect and separate the eruptions of Lower-Silurian time from those of the Lower Old Red Sandstone.

Upper-Silurian Volcanoes.—The latest volcanic eruptions of Silurian time yet definitely known took place during the accumulation of the Llandovery, Wenlock, and Ludlow rocks in the far west of Ireland. No satisfactory record of any contemporaneous phenomena of a like kind has yet been met with in any other Upper-Silurian district in the British Isles. There were at least two distinct and widely separated centres of activity. One of these lay in what is now the wild mountainous tract between Lough Mask and the sea, along the borders of Counties Mayo and Galway. The other is to be sought among the headlands of Kerry, where the land projects farthest west into the stormy Atlantic. The occurrence of the volcanic rocks in these remote areas and their geological horizon have been clearly indicated on the maps of the Geological Survey. Thirty years, however, have elapsed since some of the mapping was done, and we must therefore be prepared to find it, more especially in its petrography, capable of modification and improvement now.

The more northerly of the two districts embraces a tract of singularly rugged ground, composed in great part of conglomerates

and grits of Upper-Silurian age. The coarseness and thickness of these conglomerates, and their appearance on so many successive horizons, probably indicate a time of considerable terrestrial disturbance. It was during such a time that volcanic action broke out in this region. Lavas and agglomerates were thrown out together with fine tuffs. These rocks extend in a nearly continuous band along the hillsides that form the north-western boundary of Lough Mask to beyond Lough Nafooey. According to the mapping of the Geological Survey, the volcanic rocks lie in the higher part of the Upper-Silurian deposits *. My own observations in this district have been too limited to allow of my offering a satisfactory summary of its volcanic geology. I found in the country about Lough Nafooey that the lavas consist of finely crystalline or compact porphyrites, varying from a dull-green to a chocolate-purple colour, frequently amygdaloidal, and becoming cellular on weathered surfaces by the decay of the amygdules. The vesicular structure is not equally diffused through the mass, but appears in slaggy patches, the cavities being often elongated in the direction of flow. These rocks present the closest resemblance externally to the porphyrites of the Lower Old Red Sandstone. An average specimen prepared as a thin slice shows under the microscope a congeries of minute lath-shaped microliths of felspar with disseminated patches of iron ore.

Intercalated with the lavas are bands of coarse agglomerate, made up chiefly of large and small blocks of similar porphyrites, often remarkably slaggy, and embedded in a compact matrix of more finely comminuted materials of the same nature. Among the fragments may also be observed pieces of horny felsite, red jasper, and baked shale. The whole volcanic group, which includes a number of successive beds of lava and pyroclastic materials, rests upon conglomerates, grits, and shales, and dips underneath fossiliferous sandstones, shales, and fine conglomerates.

In that wild part of County Kerry known as the Dingle promontory, traces of contemporaneous volcanic rocks are to be observed at various localities and on several horizons. To the east, near Anascaul, on the northern shore of Dingle Bay, some tuffs occur in what are believed to be Llandovery strata. But it is on the western coast, among the headlands and coves that lie to the north and south of Clogher Head, that the best sections are to be seen. The succession of the rocks in this locality was well worked out by Du Noyer, and the memoir prepared by him, with the general introduc-

* See Sheets 84, 85, 94, and 95 of the Geol. Survey of Ireland, with corresponding Explanation.

tion by Jukes, is an invaluable guide to the geologist who would explore this somewhat inaccessible region *. The most important correction that will require to be made in the work arises from a mistake as to the true nature of certain rocks which were described as pisolitic tuffs, but which are nodular felsites.

By far the most striking geological feature of this singularly interesting and impressive coast-line is to be found in the interstratification of lavas with bands of tuff among abundantly fossiliferous strata which, from their organic contents, are unmistakably of the age of the Wenlock group. These lavas occur in a number of sheets, separated from each other by tuffs and other fragmental deposits. They thus point to a series of eruptions over a sea-bottom that teemed with Upper-Silurian life. They consist for the most part of remarkably fine typical nodular felsites. The nodules vary in dimensions from less than a pea to the size of a hen's egg. They are sometimes hollow and lined with quartz-crystals. They vary greatly in number, some parts being almost free from them and others entirely made up of them. The matrix, where a fresh fracture can be obtained, is horny in texture, and often exhibits an exceedingly beautiful and fine flow-structure. On weathered faces there may be seen thick parallel strips and lenticles of flow-structure like those of the Snowdon lavas. The upper portions of some of the sheets enclose fragments of foreign rocks. The microscopic examination of a few slices cut from these lavas shows them to be true felsites (rhyolites) composed of a microcrystalline aggregate of quartz and felspar, with layers and patches of cryptocrystalline matter, and only occasional porphyritic crystals of orthoclase and plagioclase.

The pyroclastic rocks associated with these lavas vary from exceedingly fine tuff to coarse agglomerate. Some of the finer tuffs contain pumiceous fragments and pieces of grey and red shale; they pass into fine ashy sandstones and shales, crowded with fossils, and into gravelly breccias made up of fragments of different volcanic rocks.

But the most extraordinary of these intercalated fragmental strata is a breccia or agglomerate, about 15 feet thick, which lies in a thick group of fossiliferous dull-yellow, ashy, and ochreous sandstones. The stones of this bed consist chiefly of blocks of different felsites, varying up to three feet in length. Some of them show most perfect flow-structure; others are spongy and cellular, like

* Sheets 160 and 171 of the one-inch map, and Memoir on Sheets 160, 161, 171, and 172.

lumps of pumice. The calcareous sandstone on the top of the breccia is crowded with fossils chiefly in the form of empty casts, and the same material, still full of brachiopods, crinoids, corals, &c., fills up the interstices among the blocks down to the bottom of the breccia, where similar fossiliferous strata underlie it.

Nowhere has the volcanic history of a portion of Palæozoic time been more clearly and eloquently recorded than in this remote line of cliffs, swept by the gales of the Atlantic. We see that the ordinary sedimentation of Upper-Silurian time was quietly proceeding, fine mud and sand being deposited, and enclosing the remains of the marine organisms that swarmed over the sea-bottom, when volcanic eruptions began. First came discharges of fine dust and small stones, which sometimes fell so lightly as not seriously to disturb the fauna on the sea-floor, but at other times followed so rapidly and continuously as to mask the usual sediment and form sheets of tuff and volcanic gravel. Occasionally there would come more paroxysmal explosions, whereby large blocks of lava were hurled forth until they gathered in a thick layer over the bottom. But the life that teemed in the sea, though temporarily destroyed or driven out, soon returned. Corals, crinoids, and shells found their way back again, and fine sediment carried their remains with it and filled up the crevices. The ejected volcanic blocks are thus enclosed in a highly fossiliferous matrix.

A succession of lava-streams, of which the strongly nodular sheet of Clogher Head is the thickest and most conspicuous, mark the culmination of the volcanic energy, and show how at this late part of the Silurian period felsites that reproduce some of the most striking peculiarities of earlier time were once more poured out at the surface. A few more discharges of tuff and the outflow of a greenish flinty felsite brought this series of eruptions to an end, and closed in Britain the long and varied record of older Palæozoic volcanic activity.

I am tempted to offer here, in conclusion, a general summary of the main conclusions as to Vulcanism which the array of facts I have now brought forward seems to warrant. But I have already trespassed too long on your kind indulgence. With your permission, therefore, I will reserve such statement of results until on another occasion I have been enabled to lay before you a review of the remaining periods in the long volcanic history of our country.

February 25, 1891.

Dr. A. Geikie, F.R.S., President, in the Chair.

Ernest A. Floyer, Esq., F.L.S., Helwan, Egypt; John Blockley Jaquet, Esq., A.R.S.M., 8 Alwyne Square, N.; Alfred Vaughan Jennings, Esq., F.L.S., Curator of the Eton-College Museum, 8 Broadhurst Gardens, South Hampstead, N.W.; Thomas Leighton, Esq., Lindisfarne, St. Julian's Farm Road, West Norwood, S.E.; Thomas William Reader, Esq., 171 Hemingford Road, Barnsbury, N.; and Arthur Robert Sawyer, Esq., A.R.S.M., Box 102, Pretoria, Transvaal, South Africa, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "A Contribution to the Geology of the Southern Transvaal." By W. H. Penning, Esq., F.G.S.

2. "On the Lower Limit of the Cambrian Series in N.W. Caernarvonshire." By Miss Catherine A. Raisin, B.Sc. (Communicated by Prof. T. G. Bonney, LL.D., F.R.S., V.P.G.S.)

3. "On a Labyrinthodont Skull from the Kilkenny Coal-Measures." By R. Lydekker, Esq., B.A., F.G.S.

The following specimens were exhibited:—

Rock-specimens and microscopic sections, exhibited by Prof. T. G. Bonney, LL.D., F.R.S., on behalf of Miss Catherine Raisin, in illustration of her paper.

Section drawn by J. Evans, Esq., exhibited by Dr. H. Hicks, F.R.S., in illustration of his remarks on the above-mentioned paper.

Specimens of gold-nuggets, rocks, plant-remains, and microscopic sections from the Transvaal, exhibited by C. J. Alford, Esq., F.G.S.

One specimen and one cast of Labyrinthodont skull, exhibited by R. Lydekker, Esq., B.A., F.G.S., in illustration of his paper.

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March 11, 1891.

Dr. A. Geikie, F.R.S., President, in the Chair.

Frederick J. Arundel Matthews, Esq., Hilly Ridge House, Headingley, Leeds; Sidney Hugh Reynolds, Esq., B.A., Trinity College, Cambridge; and John Yates, Esq., 96 Church Street,

Chelsea, S.W., were elected Fellows; and Don Antonio del Castillo, Mexico, and Prof. K. A. Lossen, Berlin, Foreign Correspondents of the Society.

The List of Donations to the Library was read.

It was announced that the next meeting of the International Geological Congress will be held at Washington (D.C.) on Wednesday, August 26th, 1891. Fellows of the Society who intend to be present should communicate with the Secretary of the Congress, 1330 F Street, Washington.

The following communications were read:—

1. "Manod and the Moelwyns." By A. V. Jennings, Esq., F.L.S., F.G.S., and G. J. Williams, Esq., F.G.S.

2. "The Tudor Specimen of *Eozoon*." By J. W. Gregory, Esq., F.G.S., F.Z.S.

The following specimens were exhibited:—

Rock-specimens and microscopic sections, exhibited by A. V. Jennings, Esq., F.L.S., F.G.S., and G. J. Williams, Esq., F.G.S., in illustration of their paper.

Specimens of *Eozoon* (including the Tudor specimen), exhibited by J. W. Gregory, Esq., F.G.S., F.Z.S., in illustration of his paper.

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March 25, 1891.

Dr. A. Geikie, F.R.S., President, in the Chair.

Richard Evans Willoughby Berrington, Esq., Assoc. Mem. Inst. C.E., Graiseley House, Wolverhampton; F. W. Edridge-Green, M.D. (Dunelm.), M.R.C.S., L.R.C.P., Waverley House, Hendon, N.W.; Robert Hay, Esq., Mem. Inst. C.E., Dunedin, New Zealand; Henry Hoyle Howorth, Esq., M.P., Bentcliffe, Eccles, Manchester; Ernest William Read, Esq., Norfolk County School, Elmham; and Francis E. Rooper, Esq., Glyn Ceiriog, Llangollen, North Wales, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "Notes on Nautili and Ammonites." By S. S. Buckman, Esq., F.G.S.

[Abstract.]

1. *The Position of the last Septum.*—Mr. Bather's theory of shell-growth in Cephalopoda (Ann. & Mag. Nat. Hist. 1888, i. p. 300) seems to depend upon the idea that the last septum in the young of *Nautilus* and *Ammonites* was always formed at a proportionately increased distance from the penultimate. A number of specimens in the Author's collection present features of septation contrary to this idea. Of *Nautilus* the Author exhibited six specimens, ranging from young examples in which the first whorl was barely completed, to larger, but still immature individuals, all showing an unduly approximate last septum; and of *Ammonites*, a series of young specimens belonging to the genera *Witchellia*, *Lioceras*, *Ludwigia*, and *Grammoceras* presenting the same feature. The Author stated that he did not put forward any theory to account for these facts.

2. *Shell-muscles of Nautili and Ammonites.*—Some of the exhibited specimens of *Nautilus* show the shell-muscles plainly; and it was pointed out that the curvature of the inner edge of the muscles and of their connecting-ligament corresponds with the curvature of the septum. Two specimens of *Ammonites* exhibited show long spatulate depressions more or less parallel to the periphery for about half the length of the body-chamber. It was suggested that these impressions indicated the position of the shell-muscles.

## Discussion.

Mr. Bather said he had always, since Oct. 1887, admitted that the last air-chamber in young specimens was sometimes relatively shallow. But he denied that, had the animal lived on, this chamber would have become deeper. Numerous specimens of the only available recent *Nautilus* proved that no septum ever moved after its deposition had once begun, and that approximation of septa was normally a character of old age alone. He had, however, insisted on the fact that "in shells of *Nautilus* and *Ammonites* a single shallow chamber occasionally intervene[d], far back in the shell, between two of normal size," and this could be seen in some of Mr. Buckman's own specimens. This he had regarded as "a purely pathological episode" due to a temporary slackening in the growth of the *animal*. Such weakness, though it might be recovered from, rendered the animal less able to resist unfavourable conditions; when an animal died young its shell naturally showed a trace of the weakness, and thus he would explain those of Mr. Buckman's specimens in which approximation of the last septum could be detected. He was therefore not inclined to depart from his previously published opinions.

Dr. Woodward remarked that he was glad to be in accord with Mr. Bather with reference to the constant proportion observable in the distance between the septa in the shells of both *Nautili* and

*Ammonites.* With regard to the closer approximation of the ultimate to the penultimate septum in the recent *Nautilus pompilius*, he strongly deprecated the idea that the septa were in any sense *movable*, after being once formed, or that it was possible for interseptal shell-growth to take place, thus widening the distance between two septa after their formation. As shell-growth in the Mollusca was identical *in method*, whether we dealt with that of the "Water-Spondylus," with its irregularly-formed septa, or the symmetrically-formed *Nautilus*, he contended that the animal had no more communication with its shell *behind* the last-formed septum than had the polyp of a tabulated coral power to revisit or alter the portion of its corallum shut off by the last-formed tabula. The constant and steady growth of the shell-lip would, of course, increase the capacity of the body-chamber, and, in the case of the female *Nautilus*, this enlargement would be fully occupied by the fecundated ovary; but immediately after the extrusion of the eggs, the body would be greatly reduced in size, and a septum would be formed by the animal, to shut off this surplus room, no longer needed by it. In old age, fecundation would cease, shell-growth would go on more slowly, and the latest septa would be closer together. An irregularity in the distance apart of the septa, in earlier life, might very well be explained by the (female) animal having accidentally escaped fecundation. Dr. Woodward pointed out that the septa in Mr. Buckman's specimens of *Ammonites* could not very well be traced, unless sections were made.

Mr. E. T. Newton read Mr. Buckman's reply from a letter which he had received:—

"It seems to me a very easy way to dispose of adverse facts to say that the specimens must be prematurely aged or suffering from disease. So far, however, as I remember the specimens exhibited, they do not show signs of old age or disease, such as lop-sided coiling, malformed ribs, carina obsolete or to one side, partially obsolete ribs, &c. As to the disease part of the theory, I send you a specimen of *Am. subplanicosta*, lopsided and rather abnormally grown, in which the septa are strikingly farther apart than those of normally grown examples—a fact totally opposed to Mr. Bather's last contention. The specimens which I have exhibited seem to show that the suture-line was, in some manner, moved forwards after it was formed. To sweep these specimens all aside by saying they are abnormal seems to be begging the question: it is equivalent to stating that all specimens which do not fit a preconceived theory are therefore necessarily abnormal."

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2. "On the Drifts of Flamborough Head." By G. W. Lamplugh, Esq., F.G.S.

3. "On a Phosphatic Chalk with *Belemnitella quadrata* at Taplow." By A. Strahan, Esq., M.A., F.G.S. (Communicated by permission of the Director-General of the Geological Survey.)

The following specimens were exhibited :—

Specimens exhibited by S. S. Buckman, Esq., F.G.S., in illustration of his paper.

Drift-specimens exhibited by G. W. Lamplugh, Esq., F.G.S., in illustration of his paper.

Specimens and microscopic preparations of Phosphatic Chalk, exhibited by A. Strahan, Esq., M.A., F.G.S., in illustration of his paper.

Microscopic preparations of Phosphatic Chalk from Taplow, Doullens, and Ciply, exhibited by Dr. G. J. Hinde, F.G.S.

Speeton Shell-bed fossils, exhibited by R. S. Herries, Esq., F.G.S.

Specimens of the Nepheline-bearing rocks of the neighbourhood of Dunedin, N.Z., exhibited by Prof. J. W. Judd, F.R.S.

Sagittal sections of young shells of *Nautilus pompilius*, showing that the last suture is not approximate, and that a new septum begins to form at the normal distance, exhibited by F. A. Bather, Esq., M.A., F.G.S.

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April 8, 1891.

Dr. W. T. Blanford, F.R.S., Vice-President, in the Chair.

George Alfred Stonier, Esq., Wellington Street, Newtown, Sydney, New South Wales; and Byron E. Walker, Esq., St. George Street, Toronto, Canada, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. "The Cross Fell Inlier." By Prof. H. A. Nicholson, M.D., D.Sc., F.G.S., and J. E. Marr, Esq., M.A., Sec.G.S.

2. "On the Igneous Rocks of the South of the Isle of Man." By Bernard Hobson, Esq., M.Sc., F.G.S.

The following specimens were exhibited :—

Specimens from the Woodwardian Museum, Cambridge, exhibited in illustration of Messrs. Nicholson and Marr's paper.

Rock-specimens and microscopic sections, exhibited by Bernard Hobson, Esq., M.Sc., F.G.S., in illustration of his paper.

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April 22, 1891.

Dr. A. Geikie, F.R.S., President, in the Chair.

Francis Hubert Barclay, Esq., Trinity Hall, Cambridge, and Leyton, Essex, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The Secretary announced the presentation by C. Fox Strangways, Esq., F.G.S., of a photograph of an Ice-transported Boulder of Shap Granite, now lying at Seamer Railway Station, near Scarborough.

The following communications were read:—

1. "Results of an Examination of the Crystalline Rocks of the Lizard District." By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S., and Major-General C. A. McMahon, F.G.S.

2. "On a Spherulitic and Perlitic Obsidian from Pilas, Jalisco, Mexico." By Frank Rutley, Esq., F.G.S.

The following specimens were exhibited:—

Rock-specimens and microscopic sections, exhibited by Prof. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S., and Major-General McMahon, F.G.S., in illustration of their paper.

Rock-specimens and microscopic sections, exhibited by Frank Rutley, Esq., F.G.S., in illustration of his paper.

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May 6, 1891.

Dr. A. Geikie, F.R.S., President, in the Chair.

Benjamin Dunstan, Esq., Norwich Chambers, Hunter Street, Sydney, New South Wales, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On a Rhætic Section at Pylle Hill or Totter Down, Bristol." By E. Wilson, Esq., F.G.S.

2. "The Inferior Oolite of the Cotteswold Hills, with special reference to its microscopical structure." By Edw. Wethered, Esq. F.G.S., F.C.S., F.R.M S.

The following specimens were exhibited:—

Specimens exhibited by E. Wilson, Esq., F.G.S., in illustration of his paper.

Specimens and microscopic sections exhibited by E. Wethered, Esq., F.G.S., F.C.S., in illustration of his paper.

Specimen from the Rhætic Bone-bed from Blue Anchor, near Watchet, with Blende and Celestine, collected by Spencer G. Perceval, Esq. Exhibited by permission of the Director-General of the Geological Survey.

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May 27, 1891.

Dr. A. Geikie, F.R.S., President, in the Chair.

William Fischer Wilkinson, Esq., Assoc.M.Inst.C.E., Peterborough House, Harrow-on-the-Hill, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The Secretary announced the presentation by Sir J. W. Dawson, LL.D., F.R.S., K.C.M.G., of photographs of *Hylonomus Lyelli* and *Dendrerpeton acadianum*, and read the following explanatory note written by the donor:—

Note *on* Photographs *presented to the Geological Society by* Sir J. W. Dawson.

The photographs of *Hylonomus Lyelli* are from the type specimen presented to the Geological Society by Sir J. W. Dawson several years ago. It has been cleaned, and two photographs have been taken, one natural size, the other enlarged. Though less complete in regard to the skull than some other specimens, it is one of the most perfect in other respects, and shows very well the more important general characters of the skeleton.

The other photograph is from an unusually large specimen of *Dendrerpeton acadianum* obtained last summer from an erect tree at the South Joggins, Nova Scotia, and showing the mandibles, some bones of the anterior extremity, and a portion of the skull. This specimen is in the collection of Sir J. W. Dawson, and a description of it will appear in the 'Geological Magazine.'

Dr. G. J. Hinde remarked that additional interest attached to the genus *Hylonomus* from the fact that a representative of it had lately been discovered in the Burnley Coalfield, and described by Mr. A. Smith Woodward, F.G.S., in the May number of the Geol. Mag. under the name of *Hylonomus Wildi*.

The following communications were read:—

1. "On the Lower Jaws of *Procoptodon*." By R. Lydekker, Esq., B.A., F.G.S.

2. "On some recently exposed Sections in the Glacial Deposits at Hendon." By Henry Hicks, M.D., F.R.S., Sec. Geol. Soc.

The following specimens were exhibited:—

Specimens and casts exhibited by R. Lydekker, Esq., B.A., F.G.S., in illustration of his paper.

Specimens exhibited by Dr. H. Hicks, F.R.S., Sec. Geol. Soc., in illustration of his paper.

Two photographs showing fossil fish-remains on the inner surfaces of a split slab, from the Wittebergen, Orange Free State, South Africa, now in the Bloemfontein Museum, exhibited by C. J. Alford, Esq., F.G.S.

Specimens of chert, exhibited by H. W. Monckton, Esq., F.G.S.

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June 10, 1891.

Sir Archibald Geikie, LL.D., F.R.S., President, in the Chair.

A Special General Meeting was held at 7.45 p.m., before the Ordinary General Meeting, at which the following resolution was proposed by Dr. Evans, seconded by Mr. Bauerman, and carried unanimously:—

> That the Society approve the recommendation of Council that the House Steward on his retirement be granted a pension of £70 per annum for life.

Before the commencement of the general business, Prof. Blake rose, on behalf of those present at the meeting, to congratulate the President on the honour that it had pleased Her Majesty to confer upon him. No one who knew him could fail to appreciate how thoroughly it was deserved; and the Geological Society would doubtless feel also the honour conferred on their science in the person of their President and the Head of the Geological Survey of the United Kingdom.

The Rev. Robert Ashington Bullen, B.A. (Lond.), University College, London, and Shoreham Vicarage, Sevenoaks; Walter Hepworth Collins, Esq., F.C.S., Bradford Buildings, Mawdsley Street, Bolton, Lancashire; Alfred Walter Lucas, Esq., Queen's Park, Chester; and Thomas de Courcy Meade, Esq., M.Inst.C.E., The Park, Highgate, N., were elected Fellows of the Society.

The List of Donations to the Library was read.

The PRESIDENT referred to the services of the late Dr. Duncan, and suggested that in the name of the Society a message of cordial sympathy should be sent to Mrs. Duncan on the great loss which had befallen her. This proposal was approved by the Fellows present; and the SECRETARY was requested to communicate with Mrs. Duncan.

The names of certain Fellows were read out for the first time, in conformity with the Bye-laws, Section VI. Article 5, in consequence of the non-payment of arrears of contributions.

The following communications were read :—

1. "Note on some Recent Excavations in the Wellington College district." By the Rev. A. Irving, B.A., D.Sc., F.G.S.

[Abstract.]

This paper furnishes new facts of Bagshot stratigraphy obtained from open sections since the Author's last paper was read on Nov. 12th, 1890. The whole sequence of the beds, as given in the published section of the College Well, has now been verified at their respective outcrops; percentages of clay in the beds laid open in excavations in March last along the critical portion of the ground are given as results of mechanical analyses of samples of them; and the northerly attenuation of the green-earth series and of the quartz-sand series is reduced to a question of mere measurement, for which the requisite data are now to hand.

The Author claims to have demonstrated that the mapping of the Geological Survey contradicts itself; that later workers in adopting this as the basis of their work along the South-Eastern Railway have fallen into serious error; and that a complete contradiction is given by the facts to the adverse criticisms offered on his corrected section along the railway, which was exhibited in November last, and is reproduced for the present paper.

DISCUSSION.

Mr. MONCKTON thought the line of argument adopted by the Author to prove the thinning-out of the green-coloured beds of the Middle Bagshot was scarcely applicable to such variable strata as the Eocene. The Author laid great stress on percentages of clay; but, as clay constantly occurs in the Lower Bagshot, that class of evidence is of little value.

Mr. Herries remarked on the resemblance between this paper and the last on the same subject. The Author tried to make his section pass muster by an ingenious use of double numbers for the various beds. This numbering had its origin in the Wellington-College well-section, which Dr. Irving took as a type. His bed 9 and 10, however, which was chiefly in dispute, had unfortunately, by his own admission, departed widely from its original type, which was a homogeneous clay. It appeared to admit of the most remarkable variations, but yet was always recognizable. The Author called it a loam, an ambiguous term, on the meaning of which the correctness of the section to a great extent depended. This so-called loam, according to the paper, contained 50 per cent. of sand in one case, and in another as much as 75; the latter the speaker would prefer to call a clayey sand, and the former was at least as much a sand as a clay. This could not be referred to the homogeneous clay which formed the basal bed of the Middle Bagshot in the well-section, but was in all cases a phase of the clayey sands of the Lower Bagshot.

The President remarked that, though he had little personal knowledge of the ground described in the paper, he had confidence in the ability of the members of the Geological Survey by whom it had been mapped. These gentlemen were not able to be present at the meeting, but they probably felt with him that life is short and the Bagshot beds are long, and that they were hardly likely to convince Dr. Irving of the correctness of their mapping by any additional argument they could use.

2. "Notes on some Post-Tertiary Marine Deposits on the South Coast of England." By Alfred Bell, Esq. (Communicated by R. Etheridge, Esq., F.R.S., F.G.S.)

[Abstract.]

The Author's object in this paper is to trace the successive stages in the development of the present coast of the north side of the English Channel, and to ascertain the sources of the diversified faunas.

The first traces of marine action on the South Coast in post-Tertiary times are found on the foreshore in Bracklesham Bay. The Author's reading of the section is somewhat different from that of the late Mr. Godwin-Austen; and he divides the marine series into (1) an estuarine clay with mollusca common to estuarine flats; (2) a compact hard mud; and (3) a bed of fine sandy silt with many organisms. These beds indicate a change from estuarine to deep-water conditions. A full list of the Selsey fossils is given, including, amongst other animals, upwards of 200 mollusca. Of 35 species of mollusca not now living in Britain, the majority exist in Lusitanian, Mediterranean, or African waters; furthermore, nearly 45 per cent. of the mollusca are common to the older Crags of the Eastern

counties. The Author considers the fauna of the Portland Bill shell-beds to indicate the further opening of the Channel subsequent to the formation of the Severn Straits, and believes that this fauna represents the deposits wanting between the Selsey mud-deposits and the erratic blocks which, according to him, overlie the mud; these Portland shells indicate an intermediate temperature "rather southern than northern" according to Dr. Gwyn Jeffreys.

In conclusion, details concerning still newer beds are given, and lists of fossils found therein; and the Author observes that there is no evidence to show when the English Channel finally opened up, beyond the suggestion of Mr. Godwin-Austen that, if the Sangatte beds and the Coombe Rock are of the same period, it must have taken place after their formation.

## Discussion.

Mr. Etheridge was well aware of the work Mr. A. Bell had done and was still doing relative to the Pliocene and post-Pliocene deposits of Britain, more especially the distribution of the mollusca along the East and South coasts of England and Eastern Ireland. The tables prepared by Mr. Bell will be found to be of considerable value, those relating to Ireland having more than ordinary interest through being for the first time presented in correlation with the English deposits. The four grants from the British Association for the years 1887 to 1889 inclusive were devoted to a re-investigation of the "Manure Gravels" of the S.E. of Ireland. The Reports appear for each year in their respective volumes, and the specimens obtained by Mr. Bell are placed in the National Collection, British Museum, Cromwell Road, South Kensington. Mr. Etheridge believed that the paper by Mr. Bell would be of value to all who are investigating the later phases in the history of the post-Pliocene deposits of the British Islands.

Mr. Clement Reid, during the Drift Survey of the Sussex coast, had found that the large erratics of Selsey and Pagham usually lay at the base of the Coombe Rock, resting directly on Eocene or Cretaceous strata. He had succeeded, however, in tracing them to a lower horizon, having found blocks at the base of the marine deposit described by Mr. Bell; he therefore could not agree with the Author in considering the transport of the erratics to be of later date than the deposition of the clays with southern shells; the evidence seems to point to an earlier period of floating ice, then to a warmer sea, and afterwards to a colder period during which the Coombe Rock was formed. The freshwater marls and the *Scrobicularia*-clays were probably of much later date.

Prof. Hull desired to know from Mr. Etheridge whether the comparison of the shells from the Wexford gravels with those of the Crag deposits led him to consider the former as being of Pliocene age, as his own observations of the stratigraphical relations of the Wexford gravels had led him to the conclusion that they were of

inter-Glacial age, and represented the "limestone-gravel beds" of the central plain of Ireland.

The Author, in reply to Mr. Reid, pointed out that the marine deposit near the Chichester hills had no relations with the "mud deposit," but belonged to the series of pebble- or gravel-beds overlying it. Referring to Prof. Hull's remarks upon the age of the Wexford gravels, he gave his reasons for having suggested their age to be pre-Glacial, probably equal in time to the East-Anglian Weybourn sands.

The following specimens were exhibited:—

Specimens exhibited by the Rev. A. Irving, B.A., D.Sc., F.G.S., in illustration of his paper.

Specimens exhibited by A. Bell, Esq., in illustration of his paper.

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June 24, 1891.

Sir Archibald Geikie, D.Sc., LL.D., F.R.S., President, in the Chair.

The Rev. Joseph Cater, M.A., The Rectory, Bisley, Woking; James Rutland, Esq., The Gables, Taplow; and Thomas Winter, Esq., County School, Elmham, Norfolk, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following names of Fellows of the Society were read out for the second time, in conformity with the Bye-laws, Section VI. Article 5, in consequence of the non-payment of arrears of contributions:—R. Betley, Esq.; Rev. G. Clements; Rev. J. M. Curran; F. L. Garrison, Esq.; F. B. Henderson, Esq.; R. W. Macleod, Esq.; J. C. Margetson, Esq.; Rev. E. C. Pritchard; C. B. Renshaw, Esq.

The following communications were read:—

1. "On Wells in West-Suffolk Boulder-Clay." By the Rev. Edwin Hill, M.A., F.G.S.

2. "On the Melaphyres of Caradoc, with Notes on the Associated Felsites." By Frank Rutley, Esq., F.G.S.

3. "Notes on the Geology of the Tonga Islands." By J. J. Lister, Esq., M.A. (Communicated by J. E. Marr, Esq., M.A., F.R.S., Sec.G.S.)

4. "On the Inverness Earthquakes of November 15th to December 14th, 1890." By C. Davison, Esq., M.A. (Communicated by Prof. Charles Lapworth, LL.D., F.R.S., F.G.S.)

The following specimens were exhibited :—

Rock-specimens and microscopic sections, exhibited by Frank Rutley, Esq., F.G.S., in illustration of his paper.

Rock-specimen and microscopic sections, exhibited by J. J. Lister, Esq., in illustration of his paper.

Specimens of Flint, Agate, &c., exhibited by E. Charlesworth, Esq., F.G.S.

Two specimens of the distal end of the left quadrate bone of a Pterodactyl discovered in the Cretaceous Formation near Bahia, Brazil, by Joseph Mawson, Esq., F.G.S., exhibited by A. Smith Woodward, Esq., F.G.S.

# ADDITIONS

TO THE

## LIBRARY AND MUSEUM OF THE GEOLOGICAL SOCIETY.

Session 1890–91.

## ADDITIONS TO THE LIBRARY.

### 1. Periodicals and Publications of Learned Societies.

*Presented by the respective Societies and Editors, if not otherwise stated.*

Acireale. Società Italiana dei Microscopisti. Bolletino. Vol. i. Fasc. 4. 1891.

Adelaide. Royal Society of South Australia. Transactions. Vol. xiii. Part 2. 1890.

R. Tate. On the Geological and Botanical Features of Southern Yorke-Peninsula [continuation], 113.—R. Tate. On the Discovery of an Older Pliocene Formation in South Australia, 172.—R. Tate. On the Stratigraphical Relations of the Tertiary Formations about Adelaide, 180. —R. Tate. The Gastropods of the Older Tertiary of Australia, Part III., 185.

Albany. New York State Museum of Natural History. Bulletin. Nos. 7 & 8. 1889.

J. C. Smock. First Report on the Iron Mines and Iron-Ore Districts in the State of New York, 1.

——. ——. Bulletin. Nos. 9 & 10. 1890.

J. C. Smock. Building-Stone in New York, 193.

——. ——. Memoirs. Vol. i. No. 1. 1889.

C. E. Beecher and J. M. Clarke. The Development of some Silurian Brachiopoda, 1.

——. ——. See also Books, New York.

Barnsley. Midland Institute of Mining, Civil, and Mechanical Engineers. Proceedings. Vol. xii. Part 108. 1891.

Barnsley. Midland Institute of Mining, Civil, and Mechanical Engineers. Proceedings. October 1889 to January 1890. 1890.

R. Russell. The Geology of the southern portion of the Yorkshire Coal-field, 41.

——. ——. ——. General Meeting at Sheffield, May 13, 1890. (Reprinted from the Proceedings of the Federated Institution of Mining Engineers. Vol. i. 1890. Pp. 81–128. 8vo. London, 1890.)

J. Nevin. On the difference between the Seams in the Northern and Southern Parts of the Yorkshire Coal-field, as shown in some of the deeper sinkings, 123.

Basel. Schweizerische paläontologische Gesellschaft. Abhandlungen. Vol. xvii. (1890). 1890. *Purchased.*

R. Haeusler. Monographie der Foraminiferenfauna der schweizerischen Transversarius-Zone, No. 1.—L. Rütimeyer. Uebersicht der eocänen Fauna von Egerkingen, nebst einer Erwiederung an Prof. E. D. Cope, No. 2.—J. Früh. Zur Kenntniss der Gesteinbildenden Algen der Schweizer-Alpen, No. 3.—J. Haas. Kritische Beiträge zur Kenntniss der jurassischen Brachiopodenfauna des schweizerischen Juragebirges und seiner angrenzenden Landestheile, ii. Theil. No. 4.—P. de Loriol et E. Koby. Etudes sur les Mollusques des Couches Coralligènes Inférieures du Jura Bernois, ii. partie, No. 5.

Bath Natural History and Antiquarian Field-Club. Proceedings. Vol. vii. No. 1. 1890.

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Belfast Natural History and Philosophical Society. Report and Proceedings for 1889–90. 1890.

J. Brown. Notes on the Musical Sand of Eigg, 23.

—— Naturalists' Field Club. Annual Report and Proceedings. 1890–91. Series 2. Vol. iii. Part 4. 1891.

Belgrad. Annales Géologiques de la Péninsule Balkanique. Dirigées par J. M. Žujović. Tome ii. 1890.

P. Pavlović. La faune méditerranéenne de Rakovica, 9 (17).—M. Blagojević. Analyses de quelques minéraux de Serbie, 61 (164).—S. Lozanić. Analyses des eaux, 79 (157, 188).—J. M. Žujović. Institut géologique de la Haute Ecole, Rapport pour les années 1880–88, 84.—M. Petrović. Analyses des terres de Bosnie, 115 (70).—M. S. Dinić. Les roches éruptives aux environs de Sophia, 121 (109).—J. M. Žujović. Excursion au M. Povlen, 169 (192).—J. M. Žujović. La météorite de Jelica, 117 (2).—A. Stanojević. Les roches éruptives de Slatina et de Rajac, 191 (188).—Ž. Jurisić. Les puits de Mačva, 193 (190).—H. Traube. Cinabre et calomel des mines "Avala," 191 (169).—Loczka. Analyse d'un mispickel du mont Avala, 210 (184).—J. M. Žujović. Les Lamprophyres de Serbie (76).—S. Lozanić. Les charbons fossiles de Serbie (186). [Papers with pages in ( ) are in Part ii. in French.]

Berlin. Deutsche geologische Gesellschaft. Zeitschrift. Band xli. Heft 4. 1890.

M. Blanckenhorn. Pteropodenreste aus der Oberen Kreide Nord-Syriens und aus dem hessischen Oligocän, 593.—A. Schreiber. Glacialerscheinungen bei Magdeburg, 603.—A. Krause. Ueber Obere Kreide-Bildungen an der pommerschen Ostseeküste, 609. — H. Trautschold. Ueber vermeintliche Dendrodenten, 621.—K. Picard. Ueber einige seltenere Petrefacten aus Muschelkalk, 635.—G. Gürich. *Ditrochosaurus capensis*, ein neuer Mesosaurier aus der Karooformation Süd-Afrikas, 641. —O. Jaekel. Ueber das Alter des sogen. Graptolithen-Gesteins, mit besonderer Berücksichtigung der in demselben enthaltenen Graptolithen, 653.—E. Liebetrau. Beiträge zur Kenntniss des Unteren Muschelkalks bei Jena, 717.—A. Remelé. Ueber einige Glossophoren aus Untersilur-Geschieben des norddeutschen Diluviums, 762.—J. Walther. Ueber die Geologie von Capri, 771.

——. ——. ——. Band xlii. Hefte 1–4. 1890. 1890–91.

K. Vogelsang. Beiträge zur Kenntniss der Trachyt- und Basaltgesteine der hohen Eifel, 1.—A. von Koenen. Ueber Dislokationen auf Rügen, 58.—F. Rinne. Ueber morphotropische Beziehungen zwischen unorganischen Sauerstoff- und Schwefelverbindungen, 63.—W. Dames. *Anarosaurus pumilio*, nov. gen. nov. sp., 74.—O. Jaekel. Ueber die systematische Stellung und über fossile Reste der Gattung *Pristiophorus*, 86.—C. Ochsenius. Ueber das Alter einiger Theile der (südamerikanischen) Anden, III., 121.—A. Philippson. Ueber die Altersfolge der Sedimentformation in Griechenland, 150.—Sapper. Ueber Erderschütterungen in der Alta Verapaz, 160.—A. Baltzer. Lössähnlich Bildungen im Canton Bern, 164.—E. Naumann. *Stegodon Mindanensis*, eine neue Art von Uebergangs-Mastodonten, 166.—A. Martin. Die phonolithischen Gesteine des Laachersee-Gebiets und der Hohen Eifel, 181.—P. Počta. Ueber einigen Spongien aus dem *Cuvieri*-Pläner von Paderborn, 217.—F. Hornung. Zur Kenntniss des Gangsystems des Auerberges im Harze und die Füllung desselben, 233.—H. Credner. Die Stegocephalen und Saurier aus dem Rothliegenden des Plauen'schen Grundes bei Dresden, 240.—J. Felix. Beiträge zur Kenntniss der Gattung *Protosphyraena*, Leidy, 278.—F. W. Pfaff. Ueber Schwankungen in der Erdanziehung, 303.—M. Blanckenhorn. Das Eocän in Syrien, mit besonderer Berücksichtigung Nord-Syriens, 318.—F. Römer. *Plagioteuthis*, eine neue Gattung dibranchiater Cephalopoden aus dem Russischen Jura, 360.—H. Kunisch. Labyrinthodonten-Reste des oberschlesischen Muschelkalkes, 377.—F. Schrodt. Beiträge zur Kenntniss der Pliocänfauna Süd-Spaniens, 386.—J. Walther. Ueber eine Kohlenkalk-Fauna aus der ägyptisch-arabischen Wüste, 419.—W. Salomon. Geologische und petrographische Studien am Monte Aviólo im italienischen Antheil der Adamellogruppe, 450.—A. von Strombeck. Ueber den oberen Gault mit *Belemnites minimus* bei Gliesmarode, unweit Braunschweig, 557.—H. Trautschold. Ueber *Megalopteryx*, 575.—F. J. P. van Calker. Ueber ein Vorkommen von Kantengeschieben und von *Hyolithus*- und *Scolithus*-Sandstein in Holland, 577.—G. Berendt. Noch einmal die Lagerungsverhältnisse in den Kreidefelsen auf Rügen, 583.—E. Haase. Beiträge zur Kenntniss der fossilen Arachniden, 631.—T. Lange. Beiträge zur Kenntniss der Flora des Aachener Sandes, 658.—A. Rotphletz und V. Simonelli. Die marinen Ablagerungen auf Gran Canaria, 677.—J. Lemberg. Zur mikrochemischen Untersuchung einiger Minerale, 737. —O. Jaekel. *Oracanthus bochumensis*, n. sp., des deutschen Kohlengebirges, 753.—J. Siemiradski. Ueber eine Endmoräne der ersten Vergletscherung unterhalb Krakau an der Weichsel und die Natur der dortigen

Lössbildungen, 756.—P. Oppenheim. Die Geologie der Insel Capri, 756. —Steinmann. Einige Fossilreste aus Griechenland, 764.—W. Müller. Kalkspath von Rothenzechau im Kreise Hirschberg in Schlesien, 771.—O. Jaekel. Ueber *Coccosteus*, 773.

Berlin. Deutsche geologische Gesellschaft. Zeitschrift. Register zu dem xxxi. bis xl. Bande, 1879–88.

——. Königlich preussische Akademie der Wissenschaften. Sitzungsberichte, 1889. Nos. 1–53. 1890.

H. Braumhauer. Ueber die Abhängigkeit der Ätzfiguren des Apatit von der Natur and Concentration des Ätzmittels, 447.—C. Rammelsberg. Ueber die chemische Natur der Turmaline, 679.—C. Klein. Krystallographisch-optische Untersuchungen an Rhadizit, Jeremejewit, Analcim, Chasbasit und Phakolith, 703.—W. Dames. Ueber die Schichtenfolge der Silurbildungen Gotlands und ihre Beziehungen zu obersilurischen Geschieben Norddeutschlands, 1111.—F. Rinne. Ueber die Umänderungen welche die Zeolithe durch Erwärmen bei und nach dem Trübewerden erfahren, 1163.

——. ——. ——, 1891. Nos. 1–24. 1891.

——. Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate. Band xxxviii. Hefte 4 & 5. 1890.

*Abhandlungen.* = Proceedings

R. Siegemann. Vorkommen, Gewinnung und Verarbeitung von Erzen in Hualgayoc (Peru), 555.—M. Kohlmorgen. Berg- und Hüttenmännische Mittheilungen über die Provinz Tarma in Peru, 302.

——. ——. Atlas. Tafel 26–29. 1890.

——. ——. Band xxxviii. 1–3 Statistische Lieferung. 1890.

——. ——. Band xxxix. Hefte 1 & 2. 1891.

*Abhandlungen.*

Lengemann. Ueber den früheren Betrieb, die gegenwärtige Lage und die Zukunftsaussichten des staatlichen Silberbergbaues zu St. Andreasberg am Harze, 47.—F. Beuther. Das Goldland des Plinius, 55.

——. ——. Atlas. Band xxxix. Hefte 1 & 2. 1891.

Bern. Schweizer Alpenclub. Jahrbuch. Jahrgang 25, 1889–90. 1890. And Beilagen. *Purchased.*

E. v. Fellenberg. Geologische Notizen über das Lauterbrunner Wetterhorn, 562.—A. Baltzer. Zur Geologie der Schweizeralpen, 581.

——. Schweizerische naturforschende Gesellschaft. Verhandlungen. 70te Jahresversammlung. Frauenfeld, 1887. 1887.

Schweizerische geologische Gesellschaft, 89.

——. ——. ——. 71te Jahresversammlung. Solothurn, 1888. 1888.

Schweizerische geologische Gesellschaft, 135.

Bern. Schweizerische naturforschende Gesellschaft. Verhandlungen. 72te Jahresversammlung. [Sessione.] Lugano, 1889. 1890.

B. Sezione di Geologia, 35.—Rapporto della Commissione Geologica, 85.—Rapporto della Commissione dei terremoti, 89.

——. ——. ——. 73te Jahresversammlung. Davos, 1890. 1891.

E. Geologisch-mineralogische Section, 66.—Compte-rendu de la ixe réunion annuelle de la Société géologique suisse, 125.—E. Brücker. Das Klima der Eiszeit, 141.

Birmingham. Mason Science College. Calendar for the Session 1890–91. 1890.

—— Philosophical Society. Proceedings. Vol. vii. Part 1. 1889–90. 1890.

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Boston. American Academy of Arts and Sciences. Proceedings. N.S. Vol. xvi. 1889.

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——. ——. ——. N.S. Vol. xvii. 1890.

—— Society of Natural History. Memoirs. Vol. iv. Nos. 7–9. 1890.

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——. ——. Proceedings. Vol. xxiv. Parts 3 & 4. 1889–90. 1890.

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Brussels. Société Belge de Géologie, de Paléontologie et d'Hydrologie. Bulletin. Tome iii. Fasc. 7. 1889. 1890.

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——. ——. ——. Annexe. Les Origines du Bassin de l'Escaut, par Eugéne van Overloop. 8vo. Brussels, 1890.

——. ——. ——. Tome iv. Fasc 1. 1890.

*Procès-verbaux.*

L. Dollo. Première Note sur les Mosasauriens de Maestricht, 8.—F. Sacco. La Géotectonique de la Haute-Italie occidentale, 8.—P. Gourrel. La faune tertiaire marine de Carry, de Sausset et de Couronne, près Marseille, 10.—A. Rutot et E. Van den Broeck. Matériaux pour servir à la connaissance de la composition chimique des eaux artésiennes du sous-sol de la Belgique dans ses rapports avec les couches géologiques qui les renferment, 22.—L. Dollo. De la nécessité de rayer le *Mosasaurus gracilis* de la faune du Maestrichtien.—A. Rutot. Présentation de coupes minces taillées dans des rognons dolomitiques du terrain houiller du bassin de la Ruhr et montrant la structure intime des végétaux houillers, 35.—A. Flamache. Notice sur un appareil pouvant servir de sismographe, 37.—A. Piret. Note sur des explorations récentes opérées dans la Meule de Bracquegnies, 39.—E. Van den Broeck et A. Rutot. Sur un modèle réduit de la sonde portative, 46.—L. Dollo. Sur la présence du Champsosaure dans le Heersien d'Orp-le-Grand, 55.—J. Gosselet. Etude sur les travaux de Charles Lory, 56.—F. Lœwinson-Lessing. Revue bibliographique des nouvelles publications géologiques et paléontologiques russes, 77.—A. Inostranzeff. Section de géologie et de minéralogie du viii$^{me}$ Congrès des naturalistes et médecins russes à St. Pétersbourg, 90.—E. Van den Broeck et A. Rutot. Exposé préliminaire sur la cartographie agricole de la Belgique, 98.—E. Dupont. Sur des études géologico-agricoles faites en 1882 à l'occasion du recensement agricole de 1880, 105.

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Brussels. Société Royale Malacologique de Belgique. Annales. Tome xxiv. 1889.

*Mémoires.*

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*Bulletin.*

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Buckhurst Hill. Essex Field-Club. Essex Naturalist. Vol. iv. Nos. 4–12. 1890.

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——. ——. ——. Vol. v. Nos. 1–5. 1891.

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Budapest. Magyar Királyi. Földtani Interzet. (Kön. Ungarische geologische Anstalt.) Jahresbericht für 1889. 1891.

——. ——. ——. (——.) Mittheilungen aus dem Jahrbuch. Band viii. Heft 9. 1890.

J. Jankó. Das Delta des Nil, 233.

——. ——. ——. (——.) ——. Band xi. Hefte 2–5. 1890–91.

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Budapest. Magyarhoni Földtani Társulat. Földtani Közlöny. Kötet xx. Füzet 5–12. 1890.

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——. ——. ——. Kötet xxi. Füzet 1–3. 1891.

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——. See also PESTH.

Buenos Aires. Sociedad Científica Argentina. Anales. Tomo xxix. Entregas 4–6. 1890.

——. ——. ——. Tomo xxx. Entregas 1–6. 1890.

——. ——. ——. Tomo xxxi. Entregas 1–4 & 6. 1891.

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——. ——. ——. Indice General. Tomo i.–xxix. 1876–1889. 1890.

——. ——. Memoria del Presidente correspondiente al XVIII° período 1889–1890. (Suplem à la Entrega 2ª del Tomo xxx.)

Caen. Faculté des Sciences de Caen. Bulletin du Laboratoire de Géologie. 1re Année, No. 1. 1890.

A. Bigot. L'Archéen et le Cambrien dans le Nord du Massif breton et leurs équivalents dans le Pays de Galles, 1.—A. Bigot. Esquisse géologique de la Basse-Normandie, 13.

——. Société Linnéenne de Normandie. Bulletin. 4e Série. Vol. iii. 1888–89. 1890.

Eudes-Deslongchamps. Rapport sur les fossiles de la collection Jarry, 75, 92.—L. Lecornu. Les tremblements de terre en Normandie, 235, 281.

——. ——. ——. 4e Série. Vol. v. 1891. Fasc. 1. 1891.

Calcutta. Asiatic Society of Bengal. Journal. N.S. Vol. lvii. Part 2. No. 5. 1888. 1890.

——. ——. ——. N.S. Vol. lviii. Part 2. No. 5. 1889. 1890.

——. ——. ——. N.S. Vol. lix. Part 2. No. 1. 1890. 1890.

——. ——. ——. N.S. Vol. lix. Part 2. Nos. 2, 3. 1890. 1890.
L. A. Waddell. On some new and little-known Hot Springs in South Bihar, 224.

——. ——. ——. N.S. Vol. lix. Part 2. 1890. Supplement No. 1. 1890.

——. ——. Proceedings. 1890. Nos. 1–10. 1890–91.
H. J. Rainey. Note on the Barisál Guns, the existence of volcanic vents in the direction of those sounds, 8.

——. ——. ——. 1891. No. 1. 1891.

——. ——. See Books, &c., *Beveridge, H.*

——. Indian Engineering. Vol. ix. Nos. 1–19, 21–26. 1891.

Cambridge, Mass. Museum of Comparative Zoology at Harvard College. Annual Report of the Curator for 1889–90. 1890.

——. ——. Bulletin. Vol. xvi. No. 9. 1890.
J. H. Sears. On Keratophyre from Marblehead Neck, Massachusetts, 167.

——. ——. ——. Vol. xix. No. 4. 1890.

——. ——. ——. Vol. xx. Nos. 1–7. 1890.
W. B. Scott and H. F. Osborn. Preliminary account of the Fossil Remains from the White River and Loup Fork Formations, contained in the Museum of Comparative Zoology, Part II., 65.

——. ——. ——. Vol. xxi. No. 1. 1891.

Cambridge Philosophical Society. Proceedings. Vol. vii. Parts 2 & 3. 1890. 1890–91.
A. E. H. Love. On Sir William Thomson's estimate of the Rigidity of the Earth, 72.

——. Transactions. Vol. xv. Part 1. 1891.
A. E. H. Love. On Sir William Thomson's estimate of the Rigidity of the Earth, 107.

Carlisle. Cumberland and Westmoreland Association for the Advancement of Literature and Science. Transactions. No. 15. 1889–90. 1891.
J. Postlethwaite. The Deposits of Metallic and other Minerals surrounding the Skiddaw Granite, 75.

Cincinnati. Society of Natural History. Journal. Vol. xii. No. 4. 1890.
E. O. Ulrich. New Lower Silurian Bryozoa, 173.

——. ——. Journal. Vol. xiii. Nos. 1–4. 1890–91.
S. A. Miller and W. F. E. Gurley. Description of some new genera and species of Echinodermata from the Coal-Measures and Subcarboniferous Rocks of Indiana, Missouri, and Iowa, 3.—J. Moore. Description of a new species of gigantic Beaver-like Rodent, 26.—J. F. James. A Cave in the Clinton Formation of Ohio, 31.—E. O. Ulrich. New and little-known American Palæozoic Ostracoda, 104.—J. Moore. Concerning a skeleton of the great fossil Beaver, *Castoroides ohioensis*, 138.—E. O. Ulrich. New and little-known American Palæozoic Ostracoda, 173.

Colombo. Ceylon Branch of the Royal Asiatic Society. Journal. Vol. i. No. 1. Part 1. 1845.

——. ——. ——. Vol. i. No. 1. 1846–47. 1861.

——. ——. ——. Vol. i. No. 3. 1847–48. 1870.

——. ——. ——. Vol. ii. Part 1. No. 4. 1848. 1887.

——. ——. ——. Vol. ii. Part 2. 1849. 1890.
E. F. Kelaart. Notes on the Geology of Ceylon, 210.

——. ——. ——. Vol. ii. Part 2. No. 6. 1853. 1882.

——. ——. ——. Vol. ii. No. 2. (No. 7.) 1853. 1853.

——. ——. ——. Vol. ii. No. 3. (No. 8.) 1855. 1855.

——. ——. ——. Vol. iii. Part 1. No. 9. 1856–58. 1883.

——. ——. ——. Vol. iv. 1865–66. (No. 13.) 1866.

——. ——. ——. Vol. iv. 1867–70. Parts 1 and 2. (Nos. 14, 15.) 1870.

——. ——. ——. Vol. v. 1871–72. (No. 17.) 1873.

——. ——. ——. Vol. v. 1873. Part 1. (No. 18.) 1873.

——. ——. ——. Vol. v. 1874. Part 1. (No. 19.) 1874.

——. ——. ——. Vol. vii. 1881. Part 2. No. 24. 1882.

——. ——. ——. Vol. vii. 1882. Part 3. No. 25. 1884.

——. ——. ——. Vol. vii. 1882. Extra number. 1883.

——. ——. ——. Vol. vii. 1883–84. Nos. 26–29. 1885–86.

——. ——. ——. Vol. ix. 1885–86. Nos. 30–33. 1885–88.
A. M. Ferguson. Plumbago, 171.

——. ——. ——. Vol. x. Nos. 36, 37. 1890.

——. ——. Proceedings. 1873–74. 1875.

Colombo. Ceylon Branch of the Royal Asiatic Society. Proceedings. 1875–80. 1881.

——. ——. ——. 1881. 1882.

——. ——. ——. 1882. 1883.

——. ——. ——. 1883. 1884.

——. ——. ——. 1884. 1885.

——. ——. ——. 1885. 1886.

——. ——. ——. 1886. 1888.

Copenhagen. Kongelige Danske Videnskabernes Selskab. Naturvidenskabelige og Mathematiske Afhandlinger. Række vi. Band v. No. 3. 1890.

——. ——. ——. Band vii. Nos. 1 & 2. 1890.

——. ——. ——. Oversigt 1890. No. 2. 1890.

Dorpat. Naturforscher-Gesellschaft. Schriften, V. Fortsetzung der neuen Untersuchungen über die Bessel'sche Formel und deren Verwendung in der Meteorologie. 1890. (8vo.)

——. ——. Sitzungsberichte. Band ix. Heft 1. 1889. 1890.

C. Schmidt. Hydrologische Untersuchungen, LI., 2.—Von Kennel. Die Insel Trinidad, 120.

Dresden. Koeniglich mineralogisch-geologisches und prähistorisches Museum. Mittheilungen. Heft 9. 1890.

H. B. Geinitz. Ueber einige Lycopodiaceen aus der Steinkohlenformation, 1.—H. B. Geinitz. Die Graptolithen des k. Mineralogischen Museums in Dresden, 11.

——. Naturwissenschaftliche Gesellschaft Isis. Sitzungsberichte und Abhandlungen. Jahrgang 1890. Jan.–Juni. 1890.

*Abhandlungen.*

H. Engelhardt. Chilenische Tertiärpflanzen, 3.—E. Danzig. Weitere Mittheilungen über die Granite und Gneisse der Oberlausitz und des angrenzenden Böhmens, 6.

Dublin. Royal Irish Academy. Proceedings. Series 3. Vol. i. Nos. 3–5. 1890–91.

J. P. O'Reilly. On the occurrence of Idocrase in the County Monaghan, 446.—J. P. O'Reilly. On the occurrence of Serpentine at Bray Head, 503.—G. H. Kinahan. On the Killary Bay and Slieve Partry Silurian Basin, also Notes on the Metamorphic Rocks of North-west Galway (Yar-Connaught), 705.

——. ——. Transactions. Vol. xxix. Parts 14 & 15. 1891.

W. J. Sollas. Contributions to a knowledge of the Granites of Leinster, 427.

Edinburgh Geological Society. Transactions. Vol. vi. Parts 1 & 2. 1890.

R. Richardson. Darwin's Geological Work, 1.—A. Johnstone. The classification, determination, distribution, origin, and evolution of the normal micas, 17.—Hugh Miller. Note on supposed high-level shell-beds in Eastern Ross, 28.—J. Henderson. On the succession of the Lower Carboniferous Series to the west of Edinburgh, with special reference to the District around Cramond, 29.—W. Pengelly. An Old Man and Woman; or Human Bones in a Scorbicularia Bed at Newton Abbot, Dorsetshire, 37.—A. Johnstone. Improvements in the Methods of Determining the Composition of Minerals by Blowpipe Analysis, 43.—H. A. Nicholson. Address on Recent Progress in Palæontology as regards Invertebrate Animals, 53.—J. G. Goodchild. Notes on Faults, 71.—J. G. Goodchild. On some Abnormal Deposits of Limestone, 75.—E. Hull. On our Coal-Resources, 76.—H. M. Cadell. Notes on the Coal Question, 86.—R. Richardson. Observations on the Geology of a part of the Puy de Dôme district of France, 89.—J. G. Goodchild. Dolomitic Limestones, 96.—A. Johnstone. The Composition and Origin of the Rock Dolomite, 99.—A. Johnstone. A Theory of the Devitrification of Igneous Rocks, 106.—J. Wilson. Birkhill Fossils at Innerleithen, Peeblesshire, 113.—J. G. Goodchild. Notes on some Irregular Forms of Stratification, 116.—R. Richardson. Obituary notice of D. Milne-Home, 119.

Edinburgh. Royal Physical Society. Proceedings. Session 1889–90. 1891.

J. Geikie. Opening Address [Geographical Evolution of Continental Areas], 171.—R. H. Traquair. On the Structure of *Coccosteus decipiens*, Agassiz, 211.—T. Scott. Preliminary Notes on a Post-Tertiary Fresh-water Deposit at Kirkland, Leven, and at Elie, Fifeshire, 334.—R. Kidston. Notes on the Palæozoic Species mentioned in Lindley and Hutton's 'Fossil Flora,' 345.—J. Bennie. Note on a recent exposure of a "Washout" of Strata in New Redhall Quarry, 392.

——. Royal Society. Proceedings. Vol. xv. 1887–88. 1889.

E. Stecker. Contact-Phenomena of some Scottish Olivine-Diabases, 160.—C. A. Stevenson. Notice of the Recent Earthquake in Scotland, with observations on those since 1882, 259.—A. Geikie. The History of Volcanic Action during the Tertiary Period in the British Isles, 344.

——. ——. ——. Vol. xvi. 1888–89. 1889.

——. ——. ——. Session 1889–90. Vol. xvii. (pp. 1–400). 1890.

C. M. Smith. The Volcanic Eruption at Bandaisan, 65.—J. Murray and R. Irvine. On Coral Reefs and other Carbonate of Lime Formations in Modern Seas, 79.—R. H. Traquair. List of the Fossil Dipnoi and Ganoidei of Fife and the Lothians, 385.

——. ——. ——. Session 1890–91. Vol. xviii. (pp. 1–64). 1891.

J. Y. Buchanan. On the Occurrence of Sulphur in Marine Muds and Nodules, and its bearing on their Mode of Formation, 17.—R. Irvine and J. Gibson. Manganese Deposits in Marine Muds, 54.

——. ——. Transactions. Vol. xxxiii. Part 3. 1886–87. 1888.

Edinburgh. Royal Society. Transactions. Vol. xxxv. Parts 1–4. 1887–90. 1889–90.

A. Geikie. The History of Volcanic Action during the Tertiary Period in the British Isles, 21.—R. Kidston. On *Neuropteris plicata*, Sternberg, and *Neuropteris rectinervis*, Kidston, n. sp., 313.—R. Kidston. On the Fossil Flora of the Staffordshire Coal-Fields, 317.—H. M. Cadell. Experimental Researches in Mountain Building, 337.—R. Kidston. On the Fossil Plants in the Ravenhead Collection in the Free Library and Museum, Liverpool, 391.—R. Kidston. On some Fossil Plants from Teilia Quarry, Gwaenysgor, near Prestatyn, Flintshire, 419.

——. Royal Scottish Geographical Society. Scottish Geographical Magazine. Vol. i. Nos. 4–12. 1885. *Purchased.*

——. ——. ——. Vols. ii.–vi. 1886–90. *Purchased.*

——. ——. ——. Vol. vii. Nos. 1–6. 1891.

J. Geikie. On the Scientific Results of Dr. Nansen's Expedition, 79. —C. Peters. From the Mouth of the Tana to the Source-region of the Nile, 113.—Lugard. Explorations in British East Africa, 195.

Ekaterinburg. Société Ouralienne d'Amateurs des Sciences Naturelles. Bulletin. Tome xii. Livr. 1. 1889.

N. Novokrestchennykh. Recherche de terrains aurifères dans le domaine de Rostioss, à l'angle N.E. du district de Solikamsk, 1.

Falmouth. Royal Cornwall Polytechnic Society. 58th Annual Report, 1890. 1891.

Frankfurt am Main. Senckenbergische naturforschende Gesellschaft. Bericht, 1890.

Fr. Kinkelin. Eine geologische Studienreise durch Oesterreich-Ungarn, 51.—Fr. Kinkelin. Eine Episode aus der mittleren Tertiärzeit des Mainzerbeckens, 109.—A. v. Reinach. Geologisches aus der unteren Maingegend, 125.

Giessen. Oberhessische Gesellschaft für Natur- und Heilkunde. 27er Bericht, 1890.

A. Streng und G. Greim. Neue Funde von Mineralien, Gesteinen und Versteinerungen aus der Umgegend von Giessen, 114.—A. Streng. Bemerkungen über den Melanophlogit, 123.—G. Greim. Eine neue Limatula aus dem Oligocän des Mainzer Beckens, 128.—J. Uhl. Ueber eine eigenthümliche Säulenbildung im Tagebau des Braunsteinbergwerks in der Lindener Mark, 130.—J. Uhl. Ueber Regentropfenspuren ebendaselbst, 133.

Glasgow. Geological Society. Transactions. Vol. ix. Part 1 (1888–89, 1889–90). 1891.

R. Kidston. On the Fructification and Internal Structure of Carboniferous Ferns in their relation to those of Existing Genera, with special reference to British Palæozoic Species, 1.—J. Young. On the Internal Structure of the Carboniferous Corals forming the genus *Chætetes* of Fischer, 57.—R. Craig. Notes upon a Cutting in the New Kilbirnie Branch of the Lanarkshire and Ayrshire Railway, on the Farm of Gurdy, Beith, 64.—M. Forster Heddle. On New Localities for Zeolites, 72.—T. Rupert Jones. On some Estheriæ and Estheria-like Shells from the Carboniferous Shales of Western Scotland, 79.—John Young. On a

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Gloucester. Cotteswold Naturalists' Field-Club. Proceedings for 1888–89. Vol. ix. Part 4. 1890.

W. C. Lucy. Presidential Address, 1889, 309.—H. H. Winwood. Notes on a Geological Section between Tytherington and Thornby, 325.—S. S. Buckman. The relations of Dundry with the Dorset-Somerset and Cotteswold areas during part of the Jurassic period, 374.—W. C. Lucy. Remarks on the Dapple Beds of the Inferior Oolite at the Horsepools, and on some Pebbles from the Great Oolite at Minchinhampton, 388.

——. ——. —— for 1889-90. Vol. x. Part 1. 1891.

W. C. Lucy. Presidential Address, 1890, 1.—W. C. Lucy. A slight history of Flint Implements, with especial reference to our own and adjacent areas, 22.—F. Smithe. The Minerals of Gloucestershire: Observations on Celestite, 71.—A. Harker. On the Sections in the Forest Marble and Great Oolite formations, exposed by the new railway from Cirencester to Chedworth, 82.—S. S. Buckman. The Sections exposed between Andoversford and Chedworth, 94.—E. Wethered. On the occurrence of fossil forms of the Genus *Chara* in the Middle Purbeck Strata of Lulworth, Dorset, 101.

Gotha. Petermann's Mittheilungen. Band xxxvi. Nos. 8–12. 1890. *Purchased.*

H. Hergesell. Die Entstehung der Welt und die geologische Zeit, 198.—C. Sandler. Strandlinien und Terrassen, 209, 235.—H. Zoller. Meine Expedition in das Finisterre Gebirge, 233.—W. Bodenbender. Vorläufige Mittheilungen über eine Reise nach dem Ostabfall der Anden zwischen Rio Diamante und Rio Negro, 242.—J. Damian. Der Molveno-See in Tirol, 262.

——. ——. Band xxxvii. 1891. Heft 1–6. 1891. *Purchased.*

H. Lange. Aus dem Staate São Paulo, Brasilien, 12.—K. Keilhack. Ueber die Lage der Wasserscheide auf der baltischen Seenplatte, 38.—C. Mitzopulos. Die Erdbeben in Griechenland und der Turkei im Jahr 1890, 51.—W. Götz. Das Kapaonikgebirge in Serbien, 60.—E. v. Drygalski. Die Bewegung der Kontinente während der Eiszeit, 77, 127.—O. Gumprecht. Zur Entwickelung der Wasserscheiden, insbesondere der Thalwasserscheiden, im Gebiete der Julischen Alpen, 90.—F. W. Paul. Der ehemalige Gletscher des Lalathales im Rodnaer Gebirge, 98.—R. Sieger. Skandinavische Seitenstücke zur Katastrophe von Zug, 99.—P. Rudski. Die Bewegung der Kontinente während der Eiszeit, 101.—R. Hansen. Die Besiedelung der Marsch zwischen Elb- und Eidermündung, 105.—E. Naumann. Zur Geologie von Japan, 127.

Gotha. Petermann's Mittheilungen. Ergänzungsheft. No. 98. 1890. *Purchased.*
J. Partsch. Kephallenia und Ithaka, 1.

——. ——. No. 99. 1890. *Purchased.*
v. Höhnel. Ostäquatorial-Afrika zwischen Pangani und dem neuentdeckten Rudolf-See, 1.

——. ——. No. 100. 1890. *Purchased.*
G. Radde. Karabagh, 1.

Gratz. Naturwissenschaftlicher Verein für Steiermark. Mittheilungen. Jahrgang 1889. 1890.
R. Hoernes. Die geologische und paläontologische Literatur der Steiermark 1889, lxx.—C. Doelter. Neuere Arbeiten über Mineral-Synthese, 129.—E. Hatle. Vierter Beitrag zur mineralogischen Topographie der Steiermark, 141.—A. F. Reibenschuh. Chemische Untersuchung neuer Mineral-Quellen Steiermarks, 172.

Halle. Kaiserliche Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher. Verhandlungen. Band liv. 1890.

Halle-Saale. Zeitschrift für Naturwissenschaften. Band lxiii. Hefte 1–5. 1890.
E. Zache. Ueber den Verlauf und die Herausbildung der diluvialen Moräne in den Ländern Zeltow und Barnium-Lebus, 1.—E. Dunker. Ueber ein Vorkommen von Krystallen in der Formation des Keupers, 125. —L. Böttger. Geschichtliche Darstellung unserer Kenntnisse und Meinungen von den Korallenbauten, 241.—Wohltmann. Ein Beitrag zu den Muschelbergen, Sambaquis, an der Ostküste Brasiliens, 305.

Harlem. Société Hollandaise des Sciences. Archives Néerlandaises des Sciences Exactes et Naturelles. Tome xxiv. Livr. 1–5. 1890–91.

——. ——. ——. Tome xxv. Livr. 1. 1891.

Havre. Société Géologique de Normandie. Bulletin. Tome xii. Année 1886. 1887.
G. Lennier. Description des Fossiles du Cap de la Hève, 17.—E. Lemarchand. Note sur une Vertèbre d'*Elephas primigenius* des Alluvions quaternaires de la Vallée de la Seine à St. Aubin, 101.—G. Lennier. Notes sur quelques roches recueillies à la Hague, 106.

Hermannstadt. Siebenbürgischer Verein für Naturwissenschaften. Verhandlungen. Jahrgang xl. 1890.

Hertford. Hertfordshire Natural-History Society and Field-Club. Transactions. Vol. v. Part 9. 1890.

——. ——. ——. Vol. vi. Parts 1–3. 1890.
H. G. Fordham. A Record of Water-level in a deep Chalk Well at Odsey Grange, Royston, 1878–88, 31.—J. Hopkinson. On Geological Photography in Hertfordshire, 49.—W. Whitaker. Some Hertfordshire Well-sections, 53.

Hobart. Royal Society of Tasmania. Papers and Proceedings for 1889. 1890.

G. Thureau. The "Iron Blow" at the Linda Goldfield, 1.—R. M. Johnston. The "Iron Blow" at the Linda Goldfield, 21.—T. Stephens. Foraminifera in Upper Palæozoic Rocks, 54.—R. M. Johnston and A. Morton. Notes on the Discovery of a Ganoid Fish in the Knocklofty Sandstones, Hobart, 102.—R. M. Johnston. Additions to the List of Tasmanian Fossils of Upper Palæozoic Age, 137.

Jena. Paläontologische Abhandlungen. Neue Folge. Band i. Heft 3. 1890. *Purchased.*

O. Novák. Vergleichende Studien an einigen Trilobiten aus dem Hercyn von Bicken, Wildungen, Greifenstein und Böhmen, 95.

Johannesburg. The Witwatersrand Mining and Metallurgical Review. No. 4. 1890.

C. J. Alford. The Geological Features of the De Kaap Gold Fields, 1.

——. ——. No. 6. 1890.

C. J. Alford. Notes on a Salt Deposit about 25 miles North of Pretoria, Transvaal, 1.

——. ——. No. 7. 1890.

——. ——. No. 8. 1890.

J. C. Johnston. Notes on Petroleum, 4.

——. ——. No. 9. 1890.

W. H. Penning. Geology and Gold Mining, 11.

——. ——. No. 10. 1890.

C. J. Alford. Notes on an Expedition to Zoutpansber 1.—W. H. Penning. Geology and Gold Mining, 12.

——. ——. No. 12. 1890.

T. Reunert. Twenty Years of Diamond Mining.

——. ——. No. 13. 1891.

——. ——. No. 14. 1891.

——. ——. No. 15. 1891.

——. ——. No. 16. 1891.

——. ——. No. 17. 1891.

Kiel. Mineralogisches Institut der Universität Kiel. Mittheilungen. Band i. Heft 3. 1890. *Purchased.*

E. Stolley. Ueber zwei Brachyuren aus dem mitteloligocaenen Septarienthon Norddeutschlands, 151.—F. M. Stapff. Zur Diluvialfrage, 174. —E. Danzig. Ein Ausflug in's Erzgebirge, 187.

Kingston (Canada). Queen's College and University. Calendar for the year 1890–91. 1890.

Lausanne. Musée d'Histoire Naturelle. Rapports Annuels des Conservateurs pour l'année 1889. 1891. *Presented by Prof. E. Renevier, F.M.G.S.*

——. —— —— 1890. 1891. *Presented by Prof. E. Renevier, F.M.G.S.*

Lausanne. Schweizerische geologische Gesellschaft. Mittheilungen. Eclogæ Geologicæ Helvetiæ. Band i. No. 6. 1890.

E. Favre et H. Schardt. Revue géologique de 1889, 473.—L. Duparc. Composition des calcaires portlandiens, 562.

——. ——. ——. Band ii. No. 1. 1890.

C. Schmidt und G. Steinmann. Geologische Mittheilungen aus der Umgebung von Lugano, 1.—C. Schmidt. Ueber ein zweites Vorkommen von dichtem Vesuvian in den Schweizeralpen, 83.

——. Société Géologique Suisse. Eclogæ. Vol. ii. Nos. 2–4. 1890.

A. Jaccard. L'origine de l'Asphalte, du Bitume et du Pétrole, 87.—Compte rendu de la Neuvième Réunion Annuelle de la Société Géologique Suisse à Davos, 154.—v. Gilliéron. Ein Bohrversuch auf Steinsalz bei Bettingen, 199.—A. Jaccard. Les Hautes Alpes vaudoises de M. le Professeur E. Renevier, 215.—E. Renevier. Envahissement de la mer éocénique aux Diablerets, 225.—E. Renevier. Origine et âge du gypse et de la cornieule des Alpes vaudoises, 229.—E. Renevier. Transgressivité inverse, 247.—Schardt. Chaîne du Reculet-Vuache, 253.—E. Favre et Hans Schardt. Revue géologique Suisse pour l'année 1890, 345.

——. Société Vaudoise des Sciences Naturelles. Bulletin. Sér. 3. Vol. xxv. No. 101. 1890.

——. ——. ——. Sér. 3. Vol. xxvi. No. 102. 1891.

——. ——. ——. Sér. 3. Vol. xxvii. No. 103. 1891.

E. Renevier. Envahissement graduel de la mer éocénique aux Diablerets, 41.—E. Renevier. Origine et âge du gypse et de la cornieule des Alpes vaudoises, 45.—E. Renevier. Transgressivité inverse, 63.—H. Schardt. Contributions à la géologie du Jura, 69.

Leeds. Geological Association. Transactions. Part 5. 1889. 1890.

J. Ingleby. Ceylon's Isle, 9.—C. D. Hardcastle. The Physical Features of Ingleton, 16.—A. Smith Woodward. The application of the laws of Comparative Osteology to the Palæontology of the Vertebrata, 27.—W. H. Fitton. One of Nature's gems, 31.—A. Farrar. A remnant of pre-glacial England, or holiday notes on the Cromer forest-bed, 41.—S. Jefferson. Minerals as gems and precious stones, 45.—B. Holgate. Excursion to Garforth and Newthorpe, 51.—B. Holgate. Excursion to South Milford and Sherburn, 54.—W. G. Perfect. Excursion to Giggleswick and Langcliffe, 59.—J. S. Tute. Excursion to the "Haddackstones" and District, 62.—J. Field. Excursion to the Holme Valley, 65.—J. Spencer. Excursion to Hebden Bridge and Crimsworth Dean, 67.—S. A. Adamson. Excursion to Ripley, 68.—Bainbridge. Excursion to Upper Teesdale, 71.—W. Cheetham. Excursion to Eccleshill, 76.

——. Philosophical and Literary Society. Annual Report for 1889–90.

Leicester. Literary and Philosophical Society. Transactions. New Quarterly Series. Vol. ii. Parts 4–7. 1880–91.

M. Browne. Revision of a Genus of Fossil Fishes—*Dapedius*, 196.

Leipzig. Zeitschrift für Krystallographie und Mineralogie. Band xviii. Hefte 1-6. 1890. *Purchased.*

G. H. Williams. Cölestin von Mineral County, West Virginia, 1.—G. J. Brush und E. S. Dana. Ueber die Mineralfundstätte von Branchville, Connecticut, 7.—H. Baumhauer. Ueber die Winkelverhältnisse des Apatit von verschiedenen Fundorten, 31.—A. Arzruni. Vergleichende Beobachtungen an künstlichen und natürlichen Mineralien, 44.—A. Dannenberg. Cerussit, Anglesit und Calcit von der Grube Diepenlinchen bei Stolberg, 64.—H. A. Miers. Hemimorphismus und neue Flächen am Stephanit, 68.—L. Wulff. Beiträge zur Krystallstructurtheorie, 174.—A. Sauer und N. V. Ussing. Ueber einfachen Mikroklin aus dem Pegmatit von Gasern unterhalb Meissen, 192.—W. C. Brögger und H. Bäckström. Die Mineralien der Granatgruppe, 209.—P. J. Ploner. Ueber die Krystallform des Apophyllits der Seiseralpe, 337.—H. Baumhauer. Ueber Zwillinge des Kryolith, 355.—G. Flink. Ueber Pinakiolith und Trimerit, zwei neue Mineralien aus den Mangangruben Schwedens, 361.—W. C. Brögger. Ueber die morphotropischen Beziehungen des Pinakiolith und des Trimerit zu verwandten Mineralien, 377.—J. F. Williams. Manganopektolith, ein neues Pektolithähnliches Mineral von Magnet Cove, Arkansas, 386.—F. W. Clarke und E. A. Schneider. Experimentaluntersuchungen über die Constitution der natürlichen Silicate, 390.—R. Prendel. Einige Betrachtungen über Polymorphie und Mimesie, 450.—O. Lehmann. Ueber die Definition des Begriffes "Krystall," 457.—G. Smolař. Beiträge zur Berechnung der Zwillinge und Einiges über bemerkenswerthe Verwachsungen der Pyritkrystalle, 468.—L. Milch. Ueber ein neues krystallisirtes Borat von Leopoldshall, 481.—O. Lüdecke. Ueber Heintzit, 481.—L. Sohncke. Die Entdeckung des Eintheilungsprincips der Krystalle durch J. F. C. Hessel, 489.—S. Penfield. Spangolith, ein neues Kupfermineral, 499.—S. Penfield. Ueber Connellit von Cornwall, 507.—S. Penfield. Kupferkieskrystalle aus den French Creek Eisengruben, St. Peter, Chester Co., Pa., 512.—C. Schneider. Zur Kenntniss basaltischer Hornblenden, 579.—F. A. Genth. Mineralogische Mittheilungen, 585.—A. Arzruni und A. Frenzel. Ueber den Ferronatrit, 595.—H. Baumhauer. Ueber die Krystallisation des Nephelin, 611.—M. Weibull. Ueber krystallisirten Fluocerit von Österby in Dalarne, 619.—E. Nickel. Ueber die Beweisführung in der Zonenlehre, 620.—L. Buchrucker. Beitrag zur Kenntniss des künstlichen Babingtonit, 624.—R. Soltmann. Analyse eines Melanits von Oberrothweil, 628.

——. ——. Band xix. Hefte 1 & 2. 1891. *Purchased.*

H. Laspeyres und K. Busz. Mittheilungen aus dem mineralogischen Museum der Universität Bonn, iii. Theil, 8.—A. Schmidt. Mineralogische Mittheilungen, 56.—H. L. Wells. Ueber die Zusammensetzung des Pollux und dessen Vorkommen bei Hebron, Maine, 63.—R. de Neufville. Ueber ein neues Vorkommen des Enargits, 75.—L. Buchrucker. Die Mineralien der Erzlagerstätten von Leogang in Salzburg, 113.—L. J. Igelström. Plumboferrit von Nordmarken in Wermland, 167.—A. Hahn. Thomsonit von Mellweiler bei St. Wendel, 171.—J. F. Kemp. Gestreifte Magnetitkrystalle aus Mineville, Lake Champlain-Gebiet, Staat New York, 183.

Liége. Société Géologique de Belgique. Annales. Tome xvi. 2e Livraison.

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Liége. Société Géologique de Belgique. Annales. Tome xvii. 4e Livraison. 1890.

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——. ——. ——. ——. 3e Livraison. 1890.

*Bulletin.*

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——. ——. ——. ——. Livr. 5. 1890.

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Lille. Société Géologique du Nord. Annales xviii. 1890. Livr. 1–3. 1890–91.

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——. ——. Annales xix. 1891. 1e Livraison. 1891.

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Lisbon. Sociedade de Geographia. Boletim. 9e serie. Nos. 2–9. 1890.

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——. ——. Indices e Catalogos da Bibliotheca, por A. C. Borges de Figueiredo. Entrega 1. (8vo.) 1890.

——. ——. Catalogos e Indices das Publicações, por L. Cordeiro. (8vo.) 1889.

Liverpool Geological Association. Transactions. Vol. x. 1889–90. 1890.

W. Semmons. Some recent additions to British Mineralogy, 9.—C. F. Webb. A visit to Grinshill and Hawkstone Park, 11.—J. E. George. Geology and Scenery of the Isle of Wight, 13.—D. Clague. Notes on Summer Rambles in the Liverpool District, 16.—J. Wilding. The Paving Materials of Liverpool, 24.—H. C. Beasley. A visit to Warwick, 27.—J. B. Davies. Some notes from Dingle Shore, 30.—Reports of Excursions, 35.

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London. Academy. Nos. 923–973. 1890.

——. ——. Nos. 974–998. 1891.

—— Amateur Scientific Society. Proceedings. Vol. 1. Nos. 1–4. 1890–91.

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——. Analyst. Nos. 171–183. 1890–91.

——. Annals and Magazine of Natural History. Series 6. Vol. vi. Nos. 31–36. 1890. *Purchased.*

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——. ——. ——. Vol. vii. Nos. 37–42. 1891. *Purchased.*

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London. Athenæum. (Journal.) Nos. 3269–3296. 1890.

——. ——. (——.) Nos. 3297–3322. 1891.

——. ——. (——.) Parts 750–756. 1890.

——. ——. (——.) Parts 757–761. 1891.

——. British Association for the Advancement of Science. Report of the 58th Meeting. Bath, 1888. 1889.

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London. British Association for the Advancement of Science. Report of the 60th Meeting. Leeds, 1890. 1891.

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London. Chemical Society. Journal. Nos. 332–337. 1890.

——. ——. ——. Nos. 338–343. 1891.

London. City of London College. Calendar for 1890–91. 1890.

——. Colliery Guardian. Vol. lviii. Nos. 1540–1565. 1890.

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——. East India Association. Journal. Vol. xxii. Nos. 3–5. 1890.

——. ——. ——. Vol. xxiii. No. 1. 1891.

——. Edinburgh and Dublin Philosophical Magazine. Series 5. Vol. xxx. Nos. 182–187. 1890. *Presented by Dr. W. Francis, F.G.S.*

——. ——. ——. Vol. xxxi. Nos. 188–193. 1891.

——. Federated Institution of Mining Engineers. *See* Barnsley.

——. Geological Magazine. Dec. iii. Vol. vii. Nos. 7–12. 1890.

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London. Geological Magazine. Dec. iii. Vol. vii. Nos. 7–12. 1890. *Purchased.*

——. ——. ——. Vol. viii. Nos. 1–6. 1891.

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——. ——. ——. *Purchased.*

London. Geologists' Association. Proceedings. Vol. xi. Nos. 7–9. 1890. 1890–91.

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——. ——. A Record of Excursions made between 1860 and 1890, edited by T. V. Holmes and C. Davies Sherborn. 8vo. 1891. (*Library Copy.*)

——. ——. ——. ——. ——. *Purchased.*

——. ——. Brief Notes on the Geology of the Mendip Hills, by H. B. Woodward. 8vo. 1890.

——. Institution of Civil Engineers. Minutes of Proceedings. Vol. c. 1890.

——. ——. ——. Vol. ci. 1890.

——. ——. ——. Vol. cii. 1890.

——. ——. ——. Vol. ciii. 1891.

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——. ——. ——. Brief Subject-index. Vol. lix. to Vol. cii. 1879–80 to 1889–90. 1890.

——. Iron. Nos. 911–937. 1890.

——. ——. Nos. 938–993. 1891.

——. Iron and Steel Trades Journal. Nos. 1620–1646. 1890.

——. ——. Nos. 1647–1672. 1891.

London. Linnean Society. Journal. Vol. xx. Zoology. Nos. 124–125. 1890.

——. ——. ——. Vol. xxiii. Zoology. Nos. 146–147. 1890–91.

——. ——. ——. Vol. xxvi. Botany. No. 175. 1890.

——. ——. ——. Vol. xxvii. Botany. Nos. 183–188. 1890–91.

——. ——. ——. Vol. xxviii. Botany. Nos. 189–193. 1890–91.

——. Mineralogical Society. Mineralogical Magazine. Vol. ix. No. 42. 1890.

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——. ——. ——. Vol. ix. No. 43. 1891.

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——. Nature. Vol. xlii. Nos. 1078–1096. 1890.

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——. ——. Vol. xliii. Nos. 1097–1122. 1890–91.

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London. Natnre. Vol. xliv. Nos. 1123–1129. 1891.
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——. Palæontographical Society. Monographs. Vol. xliv. 1890. 1891. (Two copies.)
A. Nicholson. The Stromatoporoids. Part 3.—W. Percy Sladen. The Cretaceous Echinodermata (Asteroidea). Vol. ii., Part 1.—S. S. Buckman. The Inferior Oolite Ammonites. Part 5.—G. F. Whidborne. The Devonian Fauna of the South of England. Part 3.—P. M. Duncan. Title-pages for the supplement to the Fossil Corals.

——. Photographic Society of Great Britain. Journal and Transactions. N.S. Vol. xv. Nos. 1–8. 1890–91.

——. Physical Society of London. Proceedings. Vol. x. Part 4. 1890. 1890.

——. ——. ——. Vol. xi. Part 1. 1891. 1891.

——. Quekett Microscopical Club. Journal. Ser. 2. Vol. iv. Nos. 27–28. 1890–91.

——. *Ray Society.* See Books. Buckler, W., and Cameron, P.

——. Royal Agricultural Society of England. Journal. Ser. 3. Vol. i. Nos. 2–4. 1890.

——. ——. ——. Ser. 3. Vol. ii. Part 1. No. 5. 1891.

——. ——. ——. General Index to Second Series (1865–89). 1890.

——. Royal Astronomical Society. Memoirs. Vol. xlix. Part 2. 1887–89. 1890.

——. Royal College of Surgeons of England. Calendar, 1890. 1890.

——. ——. List of the Fellows, Members, &c. 1891.

——. Royal Geographical Society. Proceedings. Vol. xii. Nos. 7–12. 1890.
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——. ——. ——. Vol. xiii. Nos. 1–6. 1891.
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London. Royal Institution of Great Britain. Proceedings. Vol. xiii. Part 1. No. 84. 1891.

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——. Royal Meteorological Society. Quarterly Journal. Vol. xvi. Nos. 75–76. 1890.

——. ——. ——. Vol. xvii. Nos. 77–78. 1891.

——. Royal Microscopical Society. Journal. 1890. Parts 4–6. 1890.

H. W. Burrows, C. Davies Sherborn, and G. Bailey. The Foraminifera of the Red Chalk of Yorkshire, Norfolk, and Lincolnshire, 549.

——. ——. ——. 1891. Parts 1–3. 1891.

——. Sanitary Institute. Transactions. Vol. x. 1888–89. 1890.

——. ——. ——. Vol. xi. 1890. 1891.

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——. Society of Arts. Journal. 1962–1988. 1890.

W. Topley. On the Discovery of Coal in the South-east of England.

——. ——. ——. 1989–2013. 1891.

——. Society of Biblical Archæology. Proceedings. Vol. xiii. Parts 1–7. 1890–91.

——. Royal Society. Philosophical Transactions. Vol. clxxx. Part A. 1889. 1890.

——. ——. ——. Vol. clxxx. Part B. 1889. 1890.

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——. ——. Proceedings. Vol. xlvii. Nos. 289–291. 1890.

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——. ——. ——. Vol. xlviii. Nos. 292–295. 1890–91.

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——. ——. ——. Vol. xlix. Nos. 296–299. 1891.

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——. University College. Calendar. Session, 1890–91. 1890.

——. Victoria Institute. Journal of Transactions. Vol. xxiv. Nos. 93 & 95. 1890–91.

London. Zoological Society. Proceedings. 1890. Parts 2–4. 1890–91.

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——. ——. Report of the Council for the year 1890. 1891.

——. Zoological Record. Vol. xxvi. 1889. 1890. *Purchased.*

Manchester. Geological Society. Transactions. Vol. xx. Parts 20 & 21. 1889–90. 1890.

— Tonge. Notes on Coal-measure Fossils, 564.—G. H. Hollingworth. On a Tree Branch found in the Drift, 566.—T. Oldham. On the action of Centrifugal Force with regard to Geological Phenomena, 579.—W. Watts. On Nitrogen Gas in Strinesdale Tunnel, 608.—W. Watts. On the Carbonite Syndicate Explosives, 613.—C. Roeder. Notes on the Upper Permians, &c., at Fallowfield, lately laid open, 615.

——. ——. ——. Vol. xxi. Parts 1–6. 1890–91. 1890–91.

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——. Literary and Philosophical Society. Memoirs and Proceedings. Series 4. Vol. iii. 1890.

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——. ——. ——. Series 4. Vol. iv. Nos. 1–3. 1891.

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hulme Mottled Limestones, 47.—W. C. Williamson. General, morphological, and histological Index to the Author's Collective Memoirs on the Fossil Plants of the Coal-measures, Part 1, 53.—H. H. Howorth. The History and present position of the Theory of Glacier-motion, 69.

Manchester Microscopical Society. Transactions and Annual Report. 1889. 1890.

Melbourne. Geological Society of Australasia. Transactions. Vol. i. Part 5. 1891.

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——. Royal Society of Victoria. Proceedings. N.S. Vol. ii. 1890.

G. S. Griffiths. On Geological Progress, xxix.—G. Sweet. On the Discovery of Fossil Fish in the Old Red Sandstone Rocks of the Mansfield District, 1.

——. ——. Transactions. Vol. i. Part 2. 1889.

Meriden, Conn. Meriden Scientific Association. Proceedings and Transactions. Vol. iv. 1889–90. 1891.

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Mexico. Sociedad Cientifica "Antonio Alzate." Memorias. Tomo iii. Nos. 3–12. 1889–90.

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——. ——. ——. Tomo iv. Nos. 1–6. 1890–91.

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——. ——. ——. Serie 2. Vol. xxii. 1889.

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——. Società Italiana di Scienze Naturali. Atti. Vol. xxxi. 1888. Fasc. 1–4. 1888–90.

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——. ——. Vol. vi. Nos. 1–6. *Purchased.*

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Moscou. Société Impériale des Naturalistes. Bulletin. 1889. Sér. 2. Tome iii. No. 4. 1890.

M. Pavlow. Etudes sur l'histoire paléontologique des ongulés, 653.—W. Sokoloff. Kosmischer Ursprung der Bitumina, 720.

——. ——. ——. 1890. Sér. 2. Tome iv. Nos. 1–4. 1890.

A. Pavlow. Le Néocomien des montagnes de Worobiewo, 173.—E. Kislakowsky. Ueber den Meteoriten von Turgaisk, 187.—H. Trautschold. Ueber *Protopirata centrodon*, Trd., 317.—N. Krichtafowitch. Note préliminaire sur les couches interglaciales de Troïtzkoïe, Gouv. de Moscou, 525.—N. Krichtafowitch. Anzeichen einer interglaciaren Epoche in Central Russland, 527.

——. ——. Beilage zum Bulletin. Sér. 2. Tome iii. Meteorologische Beobachtungen. 1889. Hälfte 2. 1890.

——. ——. ——. Sér. 2. Tome iv. Meteorologische Beobachtungen. 1890. Hälfte 1 u. 2. 1891.

Munich. Königlich-bayerische Akademie der Wissenschaften. Abhandlungen der mathematisch-physikalischen Classe. Band xvii. Abth. 1 u. 2. 1889 u. 1891.

——. ——. Sitzungsberichte der mathematisch-physikalischen Classe. 1890. Hefte 1–4. 1890–91.

A. Blümcke und S. Finsterwalder. Zur Frage der Gletschererosion, 435.

Nancy. Société des Sciences. Bulletin. Série 2. Tome x. Fasc. 23. 22e Année. 1889. 1890.

Fliche. Note sur les Tufs et les Tourbes de Lasnez, xix, 134.

——. ——. Mémoires, 1889. 140e Année. Série 5. Tome vii 1890.

Newcastle-upon-Tyne. Midland Institute of Mining, Civil, and Mechanical Engineers. *See* Barnsley.

——. Natural-History Society. Natural-History Transactions. Vol. x. 1887–90. Part 2. 1890.

R. Howse. Note on the South Durham Salt Borings, with remarks on the Fossils found in the Magnesian-Limestone Cores, and the Geological Position of the Salt, 220.—R. Howse. Catalogue of the Local Fossils in the Museum of the Natural History Society, 227.

Newcastle-upon-Tyne. North of England Institute of Mining and Mechanical Engineers. Transactions. Vol. xxxix. Parts 1 & 2. 1891.

D. H. Bayldon. The Hauraki Gold-Mining District (northern section), Auckland, New Zealand, 34.

——. ——. ——. Vol. xl. Part 1. 1891.

——. ——. An Account of the Strata of Northumberland and Durham, as proved by Borings and Sinkings. A—B. 1878.

——. ——. ——. L—R. 1887.

——. ——. Report of the French Commission on the use of Explosives in the presence of Fire-damp in Mines. Parts I.–III. 8vo. 1890–91.

New Haven. American Journal of Science. Ser. 3. Vol. xl. Nos. 235–240. 1890.

W. J. McGee. The Southern Extension of the Appomattox Formation, 15.—J. F. Kemp. Notes on the Minerals occurring near Port Henry, N. Y., 62.—R. T. Hill. Occurrence of *Goniolina* in the Comanche Series of the Texas Cretaceous, 64.—C. E. Beecher. On the Development of the Shell in the Genus *Tornoceras*, Hyatt, 71.—J. P. Iddings and S. L. Penfield. Fayalite in the Obsidian of Lipari, 75.—E. S. Dana and H. L. Wells. On some Selenium and Tellurium minerals from Honduras, 78. —S. L. Penfield. On Connellite from Cornwall, England, 82.—F. A. Genth. Contributions to Mineralogy, No. 48, 114.—W. L. Dudley. A curious Occurrence of Vivianite, 120.—G. H. Stone. Classification of the Glacial Sediments of Maine, 122. —W. W. Dodge. Some Lower Silurian Graptolites from Northern Maine, 153.—J. P. Kimball. Siderite-basins of the Hudson River Epoch, 155.—J. D. Robertson. New Variety of Zinc Sulphide from Cherokee County, Kansas, 160.—F. P. Venable. Two new Meteoric Irons, 161.—O. C. Marsh. Notice on some Extinct Testudinata, 177.—J. D. Dana. The Rocky Mountain Protaxis and the Post-Cretaceous Mountain-making along its course, 181.—F. A. Genth and S. L. Penfield. Contributions to Mineralogy, 199.—S. L. Penfield. Chalcopyrite Crystals from the French Creek Iron Mines, St. Peter, Chester Co., Pa., 207.—C. E. Beecher. *Koninckina* and related Genera, 211.—E. E. Howell. Notice of two new Iron Meteorites from Hamilton Co., Texas, and Puquios, Chili, S. A., 223.—J. B. Tyrrell. The Cretaceous of Manitoba, 227.—L. V. Pirsson. On Mordenite, 232.—D. W. Langdon, Jr. Geology of Mont Louis Island, Mobile Bay, 236.—C. E. Beecher. On *Leptænisca*, a New Genus of Brachiopod from the Lower Helderberg Group, 238—C. E. Beecher. North American Species of *Strophalosia*, 240.—E. H. Barbour and J. Torrey, Jr. Notes on the Microscopic Structure of Oolite, with Analyses, 246.—B. K. Emerson. A description of the "Bernardston Series" of Metamorphic Upper Devonian Rocks, 263.—W. H. Melville. Metacinnabarite from New Almaden, California, 291.—C. H. Gordon. On the Keokuk Beds at Keokuk, Iowa, 295.—F. W. Clarke and E. A. Schneider. Experiments upon the Constitution of the Natural Silicates, 303.—G. F. Kunz. On five new American Meteorites, 312.—R. S. Tarr. Superimposition of the Drainage in Central Texas, 359.—B. K. Emerson. Description of the "Bernardston Series" of Metamorphic Upper Devonian Rocks, 362.—P. E. Browning. Analysis of Rhodochroisite from Franklin Furnace, New Jersey, 375.—W. F. Hillebrand. On the Occurrence of Nitrogen in Uraninite and

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New Haven. American Journal of Science. Ser. 3. Vol. xli. Nos. 241-246. 1891.

J. W. Spencer. Deformation of the Algonquin Beach and Birth of Lake Huron, 12.—A. F. Foerste. On the Clinton Oolitic Iron Ores, 28.—W. Upham. A Review of the Quaternary Era, with special reference to the Deposits of Flooded Rivers, 33.—L. V. Pirsson. On some Remarkably developed Calcite Crystals, 61.—O. C. Marsh. A Horned Antiodactyle (*Protoceras celer*) from the Miocene, 81.—W. P. Headden. Columbite and Tantalite from the Black Hills of South Dakota, 89.—N. H. Darton. Notes on the Geology of the Florida Phosphate Deposits, 102.—N. H. Darton. Record of a Deep Well at Lake Worth, Southern Florida, 105.—S. L. Penfield. Chemical Composition of Aurichalcite, 106.—C. R. Van Hise. Attempt to Harmonize some apparently conflicting Views of Lake Superior Stratigraphy, 117.—W. H. Melville. Powellite-Calcium Molybdate : a new Mineral Species, 138.—O. C. Marsh. Gigantic Ceratopsidæ, or Horned Dinosaurs of North America, 167.—J. S. Newberry. The Flora of the Great Fall Coal-field, Montana, 191.—J. W. Spencer. High-Level Shores in the region of the Great Lakes, and their Deformation, 201.—H. L. Wells. Composition of Pullucite and its Occurrence at Hebron, Maine, 213.—R. S. Tarr. The Phenomenon of Rifting in Granite, 267.—C. R. Keyes. The Redrock Sandstone of Marion County, Iowa, 273.—E. H. S. Bailey. On Halotrichite, or Feather Alum, from Pitkin County, Colorado, 296.—O. C. Farrington. On Crystallized Azurite from Arizona, 300.—O. A. Derby. On the Occurrence of Xenotime as an Accessory Element in Rocks, 308. —O. A. Derby. On the Magnetite Ore Districts of Jacupiranga and Ipanema, São Paulo, Brazil, 311.—C. F. de Landero. On Pink-Grossularite from Mexico, 321.—O. C. Marsh. Restoration of *Triceratops*, 339. —C. E. Beecher. Development of the Brachiopoda, 344.—T. C. Chamberlin and R. D. Salisbury. Relationship of the Pleistocene to the Prepleistocene of the Mississippi Basin, south of the Glaciation limit, 359.—H. V. Winchell. Geological Age of the Saganaga Syenite, 386.—F. A. Genth, S. L. Penfield, and L. V. Pirsson. Contributions to Mineralogy, Nos. 50 & 51, 394, 401.—W. P. Blake. Columbite of the Black Hills, South Dakota, 403.—H. N. Ridley. The Raised Reefs of Fernando de Noronha, 406.—T. M. Reade. The Cause of Active Compressive Stress in Rocks and Recent Rock Flexures, 409.—W. P. Headden. A new Phosphate from the Black Hills of South Dakota, 415.—W. E. Hidden and J. B. Mackintosh. Supplementary Notice on the Polycrase of North and South Carolina, 423.—F. J. H. Merrill. On the Post-Glacial History of the Hudson River Valley, 460.—W. Cross. On Alunite and Diaspore from the Rosita Hills, Colorado, 466.—W. H. Melville. Diaspore Crys-

tals, 475.—A. Lindenkohl. Notes on the Submarine [Channel of the Hudson River, and other evidences of Post-Glacial Subsidence of the Middle Atlantic Coast Region, 489.—J. C. Russell. Are there Glacial Records in the Newark System?, 499.—W. T. Brigham. On the Recent Eruption of Kilauea, 507.—C. H. Snow. Turquois in South-western New Mexico, 511.

New Haven. American Journal of Science. Ser. 3. Vol. xl. Index to Volumes xxxi.–xl. 1891.

——. Connecticut Academy of Arts and Sciences. Transactions. Vol. viii. Part 1. 1890.

O. Meyer and S. L. Penfield. Results obtained by Etching a Sphere and Crystals of Quartz with Hydrofluoric Acid, 158.

——. American Museum of Natural History. Annual Report of the Trustees, for the year 1889–90. 1880.

——. ——. Bulletin. Vol. ii. No. 3. 1889.

——. ——. ——. Vol. ii. No. 4. 1890.

E. A. Mearns. Description of supposed new Species and Subspecies of Mammals from Arizona, 277.

——. ——. ——. Vol. iii. No. 1. 1890.

E. Brainerd. The Calciferous Formation in the Champlain Valley, 1. —R. P. Whitfield. Observations on the Fauna of the Rocks at Fort Cassin, Vermont, with Descriptions of a few new Species, 25.

——. ——. ——. Vol. iii. Pp. 117-122. 1890.

R. P. Whitfield. Observations on a Fossil Fish from the Eocene beds of Wyoming, 117.—R. P. Whitfield. Description of a new Genus of Inarticulate Brachiopodous Shell, 121.

Nottingham Naturalists' Society. Transactions and 37th Annual Report. 1889.

E. Kidson. Farther Evidences of Glacial Action in Snowdonia, 14.—J. Shipman. The Geology of Nottingham, 26.

——. —— 38th Annual Report. 1890.

Oporto. Sociedade Carlos Ribeiro. Revista de Sciencias Naturaes e Sociaes. Vol. i. Nos. 1–4. 1889–90.

P. Choffat. Nouvelles publications sur les dépôts mésozoïques du Brésil, 115.

——. ——. ——. Vol. ii. No. 5. 1891.

Padua. R. Accademia di Scienze, Lettere, ed Arti. Atti e Memorie. Nuova Serie. Vol. vi. 1890.

A. de Zigno. Ofidiani trovati allo stato fossile e descrizione di due colubri scoperti nei terreni terziari del Veneto, 109.

——. Rivista di Mineralogia e Cristallografia Italiana. Vol. vi. 1890. *Purchased.*

G. B. Negri. Sugli strati di tufo basaltico dei dintorni di Teolo negli Euganei, 19.—R. Panebianco. Su di alcuni simboli delle Calcite di

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Padua. Rivista di Mineralogia e Cristallografia Italiana. Vol. vii. 1890. *Purchased.*

G. B. Negri. Studio chimico su di alcune Natroliti venete, 16.—R. Panebianco. Molibdenite ed altri minerali che accompagnano la Pseudo-tridimite di Zovon, 20.—G. Struever. Ematite di Stromboli, 21.—G. Struever. Contribuzioni allo studio dei graniti della Bassa Valsesia, 33. —E. Malard. Pseudo-tridimite dei Monti Euganei, 64.—E. Scacchi. Sulla Hauerite delle solfare di Raddusa in Sicilia, 67.—O. Silvestri. Nota preliminare sulla Hauerite di Sicilia, 68.—G. B. Negri. Note cristallografiche su di alcune Natroliti venete e Appunti critici, 69.—G. La Valle. Sull' Epidoto di Val d'Ala, 93.

——. ——. Vol. viii. Fasc. 1–3. 1890–91. *Purchased.*

L. Brugnatelli. Contribuzioni alla conoscenza dell' Epidoto, 8.—G. Grattarola. Realgar, Orpimento e minerali concomitanti di Casa Testi (Monte Amiata), 36.

Palermo. Annales de Géologie et de Paléontologie. See Books. *Gregorio, Marquis A. de.*

——. Società di Scienze Naturali ed Economiche. Giornale. Vol. xx. 1890. 1890.

G. G. Gemmellaro. La fauna dei Calcari con *Fusulina* della Valle del Fiume Sosio, nella Provincia di Palermo, 9, 47.

Palma de Mallorca. Ateneo Balear. El Ateneo. Año i. Nos. 9–10. 1890.

——. ——. ——. Año ii. Nos. 11–16. 1891.

Paris. Académie des Sciences. Comptes rendus. Tome cx. No. 24–26. 1890.

A. Lacroix. Sur les andésites et labradorites à hypersthène de la Guadeloupe, 1347.—A. Muntz. Sur la décomposition des roches et la formation de la terre arable, 1370.—A. Lacroix. Caractères crystallographiques et optiques du pyroxène obtenu par M. Daubrée dans l'eau suréchauffée, 1375.—H. Lasne. Identité de composition de quelques phosphates sédimentaires avec l'apatite, 1376.—Vernadsky. Sur la reproduction de la sillimanite et la composition minéralogique de la porcelaine, 1377.—G. Sayn. Sur la faune d'Ammonites pyriteuses barrêmiennes du Djebel-Ouach, province de Constantine, 1381.

——. ——. ——. Tome cxi. Nos. 1–26. 1890.

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Paris. Académie des Sciences. Comptes-rendus. Tome cxii. Nos. 1–8, 10–24. 1891.

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Paris. Annales des Mines. Série 8. Tome xvii. 1re–3e livraisons de 1890.

A. Carnot. Sur les eaux minérales de Cransac, 282.—Termier. Etude sur la Leverrierite, 372.

——. ——. ——. Tome xviii. 4e–6e livraisons de 1890. 1890.

J. Seunes. Recherches géologiques sur les terrains secondaires et l'éocène inférieur de la région sous-pyrénéenne du sud-ouest de la France (Basses-Pyrénées et Landes), 209.—Laurent. Notes sur l'industrie de l'Or et du Platine dans l'Oural, 537.

——. ——. ——. Tome xix. 1re livraison de 1891. 1891.

J. Thoulet. Expériences sur la sédimentation, 5.—De Launay. Les Mines d'Or du Transvaal, 102.

——. Annales des Sciences Géologiques. Tome xxi. 1891. *Purchased.*

H. Filhol. Etudes sur les Mammifères Fossiles de Sansan, 1.

Paris. Annales des Sciences Naturelles. Zoologie et Paléontologie. Série 7. Tome x. Nos. 1–6. 1890. *Purchased.*

——. ——. ——. Tome xi. Nos. 1–5. 1891. *Purchased.*

——. Annales Hydrographiques. Série 2. Volume de 1890. 1890.

——. Annuaire Géologique Universel. Année 1889. Tome vi. 1890.

——. Muséum d'Histoire Naturelle. Nouvelles Archives. Série 3. Tome 2. Fasc. 1. 1890.

——. Journal de Conchyliologie. Série 3. Tome xxx. Nos. 2–4. 1890. *Purchased.*

P. Fischer. Note sur le genre *Ammonoceras*, Lamarck, 130.—E. de Boury. Observations sur quelques Scalidæ du Bassin de Paris et description d'une espèce nouvelle, 139.—C. Mayer-Eymar. Description de coquilles fossiles des terrains tertiaires inférieurs, 353.—D. P. Œhlert. Note sur différents groupes établis dans le genre *Orthis*, et en particulier sur *Rhipidomella*, Œhlert (=*Rhipidomys*, Œhlert), 366.—P. Fischer. Diagnoses d'espèces nouvelles recueillies, à l'état subfossile, près d'El Goleah, 374.

——. ——. ——. Tome xxxi. No. 1. 1891. *Purchased.*

——. Journal des Mines. 37 Année. Nos. 27–52. 1890.

——. ——. 38e Année. Nos. 1–26. 1891.

——. Société Française de Minéralogie. Bulletin. Tomes i.–v. 8vo. 1879–82. *Purchased.*

——. ——. ——. Première Table Décennale des Matières, Volumes i. à x. Par H. Goguel. 8vo. Paris. 1888. *Purchased.*

——. ——. ——. Tome xiii. Nos. 6–10. 1890. 1890.

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——. Société Géologique de France. Bulletin. Sér. 3. Tome xvi. No. 11. 1890.

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Paris. Société Géologique de France. Bulletin. Sér. 3. Tome xviii. Nos. 1–8. 1890.

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——. ——. Mémoires. Sér. 3. Tome v. No. 2. 1891.

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——. ——. ——. Paléontologie. Tome i. Fasc. 1–3. 1890.

A. Gaudry. Le Dryopithèque, No. 1.——J. Seunes. Contributions à l'étude des Céphalopodes du Crétacé supérieur de France, No. 2.—C. Depéret. Les Animaux pliocènes du Roussillon, No. 3.—R. Nicklès. Contributions à la paléontologie du Sud-Est de l'Espagne, No. 4.—G. de Saporta. Le *Nelumbium provinciale*, No. 5.—H. Douvillé. Etudes sur les Rudistes, No. 6.

Penzance. Royal Geological Society of Cornwall. Transactions. Vol. ii. Parts 4–5. 1891.

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Pesth. Geologische Gesellschaft für Ungarn. Arbeiten. I. Heft. 1856. *Presented by C. Davies Sherborn, Esq., F.G.S.*

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Philadelphia. Academy of Natural Sciences. Proceedings, 1890. Parts 1–3. 1890–91.

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Philadelphia. American Philosophical Society. Proceedings. Vol. xxvii. No. 131. 1889. 1890.

——. ——. ——. Vol. xxviii. Nos. 132–134. 1890.

——. Wagner Free Institute of Science. Transactions. Vol. iii. 1890.

W. H. Dall. Contributions to the Tertiary Fauna of Florida, with especial reference to the Miocene Silex-beds of Tampa and the Pliocene Beds of the Caloosahatche River, Part I., 1.

Pisa. Società Toscana di Scienze Naturali. Atti. Processi Verbali. Vol. vii. pp. 199–212. 1891.

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——. ——. ——. ——. Vol. vii. pp. 213–234. 1891.

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Plymouth. Devonshire Association for the Advancement of Science, Literature, and Art. Report and Transactions. Vol. xxii. 1890.

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——. ——. ——. Extra Volume. The Devonshire Domesday. Part vii. 1890.

Rome. Reale Accademia dei Lincei. Atti. Serie 4. Memorie. Vol. v. 1888.

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——. ——. ——. Serie 4. Rendiconti. Vol. v. Fasc. 8–12. 1° Semestre, 1890. 1890.

Rome. Reale Accademia dei Lincei. Atti. Serie 4. Rendiconti. Vol. vi. Fasc. 1–12. 2° Semestre, 1890. 1890.

——. ——. ——. 1891. Ser. 4. Rendiconti. Vol. vii. Fasc. 1–8. 1° Semestre. 1891.

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——. Società Geologica Italiana. Bollettino. Vol. ix. 1890. Fasc. 2. 1890.

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Rugby School Natural-History Society. Report for the year 1890. 1891.

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St. Petersburg. Académie Impériale des Sciences. Mémoires. Sér. 7. Tome xxxvii. Nos. 8–13. 1890.

——. ——. ——. ——. Tome xxxviii. Nos. 1–31. 1890.

J. V. Rohon. Die Jura-Fische von Ust-Balei, No. 1.

San Francisco. California Academy of Sciences. Proceedings. Series 2. Vol. ii. 1889.

W. Lindgren. Petrographical Notes from Baja California, Mexico, 1.

——. ——. Occasional Papers. Nos. 1 & 2. (8vo.) 1890.

Santiago de Chile. Deutscher wissenschaftlicher Verein. (Sociedad Cientifica Alemana). Verhandlungen. Band ii. Heft 1. 1890.

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Shanghai. China Branch of the Royal Asiatic Society. Journal. N.S. Vol. xxiv. 1889–90. 1890.

Southampton. Hampshire Field-Club. Papers and Proceedings. No. 3. 1889. 1890.

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Stawell. Stawell School of Mines, Art, Industry, and Science. Annual Report and Prospectus, 1891. 1891.

Swansea. South Wales Institute of Engineers. Proceedings. Vol. xvi. No. 6. 1890.

——. ——. ——. Vol. xvii. Nos. 1–2. 1890.

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Stockholm. Geologiska Förening. Förhandlingar. Band xii. Häfte 5–7. 1890. 1890–91.

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——. ——. ——. Band xiii. Häfte 1–3. 1891.

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Stuttgart. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. Jahrgang 1890. Band ii. Hefte 2–3. 1890.

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——. ——. Jahrgang 1891. Band i. Hefte 1–3. 1891.

J. Strüver. Weitere Beobachtungen über die Minerallagerstätten des Alathals in Piemont, 1.—P. Oppenheim. Jurassische Insectenreste und ihre Deutungen, 40.—K. Martin. Eine neue Orbitolina von Santander, 58.—C. Klein. Mineralogische Mittheilungen, XII., 65.—H. Francke. Zur Litteratur über das Muttergestein des Datholiths von Theiss in Tirol, 102.—A. v. Koenen. Ueber Spiegel im Buntsandstein der Gegend von Marburg, 103.—G. Chelius und C. Vogel. Zur Gliederung des Löss, 104.—A. v. Koenen. Ueber das Alter der Schotter-Terrassen, 107.—A. Osann. Ueber Zwillingsbildung an Quarzeinsprenglingen aus liparitischen Gesteinen des Cabo de Gata, 108.—F. Zirkel. Cordieritbildung in verglasten Sandsteinen, 109.—E. Fedorow. Ueber seine beiden Werke: 1. Die Symmetrie der endlichen Figuren. 2. Die Symmetrie der regelmässigen Systeme der Figuren, 113.—C. Struckman. Die Wealdenbildungen von Sehnde bei Lehrte, 117.—J. W. Retgers. Ueber den Isomorphismus in der Dolomitreihe, 132.—J. M. Clarke. Die Fauna mit *Goniatites intumescens* im westlichen New York, 161.—A. Hedinger. Ueber den pliocänen Affen des Heppenlochs, 169.—O. Jäkel. Ueber mikroskopische Untersuchungen im Gebiet der Palaeontologie, 178.—F. v. Sandberger. Bemerkungen über einige Mineralien von Chanarcillo in Chile, 199.—A. Kenngott. Ueber die Zusammensetzung des Vesuvian, 20.—Conwentz. Ueber fossile Harze aus Nordamerika, 208.—W Deecke.

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Stuttgart. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. Beilage-Band vii. Hefte 2–3. 1890–91.

E. Weinschenk. Beiträge zur Petrographie Japans, 133.—E. A. Wülfing. Beiträge zur Kenntniss des Kryokonit, 152.—S. Czapski. Krystallrefractometer nach Abbe, 175.—H. Traube. Ueber den Molybdän-Gehalt des Scheelits und die Trennung der Wolframsäure von der Molybdänsäure, 232.—H. Wermbter. Der Gebirgsbau des Leinsthals zwischen Greene und Banteln, 246.—B. Kühn. Untersuchungen an altkrystallinen Schiefergesteinen aus dem Gebiete der argentinischen Republik, 295.—P. Sabersky. Mineralogisch-petrographische Untersuchung argentinischer Pegmatite mit besonderer Berücksichtigung der Structur der in ihnen auftretenden Mikrokline, 359.—R. Fuess. Ueber neue Erhitzungsapparate für krystallographisch-optische Studien, 406.—L. Sinigallia. Ueber einige glasige Gesteine vom Vesuv, 417.—H. Behrens. Reactionen für mikrochemische Mineralanalysen, 435.

——. Palæontographica. Band xxxvii. Lief. 1–6. 1890–91. *Purchased.*

F. Frech. Die Korallenfauna der Trias, 1.—J. Felix und H. Lenk. Uebersicht über die geologischen Verhältnisse des mexicanischen Staates Puebla, 117.—J. Felex. Versteinerungen aus der mexicanischen Jura- und Kreideformation, 140.

Sydney. Australian Association for the Advancement of Science. Report of the Second Meeting. Melbourne, Victoria, 1890. 8vo. 1890.

F. W. Hutton. Oscillations of the Earth's Surface, 67.—Report of Committee No. 7. Census of Australasian Minerals, 203.—Report of Committee No. 13. Australasian Geological Record, 357. — A. W. Howitt. Notes on the Metamorphic Rocks of Omeo, 408.—A. Liversidge. Chalk and Flints from the Solomon Islands, 417.—W. J. Clunies Ross. The Plutonic and Metamorphic Rocks of Bathurst, N.S.W., 420. —J. Hornsby. Notes on the Development of Quartzite, Maldon, 425.—F. D. Power. Notes on the Crystalline Rocks of Bethanga, Victoria, 426.—J. Park. On the Geological Structure and Future Prospects of the Thames Goldfield, New Zealand, 429.—J. Melvin. Coal: its Origin and

Process of Formation, 439.—J. Smith. Notes on an Annelid Formation in Queensland, 440.—J. Dennant. Observations on the Tertiary and Post-Tertiary Geology of South-western Victoria, 441.—E. J. Dunn. The Glacial Conglomerates of Victoria, 452.—A. Everett. Unification of the Geological Charts of Australia, Tasmania, and New Zealand, 456. —R. L. Jack. On the Thermal Springs of the Einasleigh River, Queensland, 458.—T. W. S. David. A Correlation of the Coalfields of New South Wales, 459.—J. H. Bignall. Notes on the Carboniferous Rocks of the Cape Otway District, 466.—S. H. Wintle. The Physical Conditions under which the chief Coal-measures of Tasmania and Victoria are formed, 467.—S. Ella. Some Physical Phenomena of the South Pacific Islands, 558.

Sydney. Australian Museum. Records. Vol. i. No. 1. 1890.

——. Department of Agriculture. Agricultural Gazette of New South Wales. Vol. i. Part 1. 1890.

——. ——. ——. Vol. ii. Part 3. 1891. *Presented by the Department.*

——. Linnean Society of New South Wales. Proceedings. Ser. 2. Vol. iv. Parts 3 & 4. 1890.

R. Etheridge. Note on the Fructification of *Phlebopteris alethopteroides*, Etheridge, fil., from the Lower Mesozoic Beds of Queensland, 625.—R. Etheridge. Note on the Bibliography of Lord Howe Island, 627.—J. M. Curran. Note on some Fossil Fish associated with *Tæniopteris*, from the Ballimore Series, 634.—R. Etheridge, Jun. On the Further Structure of *Conularia inornata*, Dana, and *Hyolithes lanceolatus*, Morris, sp. (= *Theca lanceolata*, Morris), 751.

——. ——. ——. Series 2. Vol. v. Parts 1–4. 1890–91.

R. Etheridge. Note on the Structure of *Annularia australis*, Feistmantel, 47.—R. Etheridge, Jun. Has Man a Geological History in Australia?, 259.—T. W. E. David. Geological Notes, 421.—R. Etheridge, Jun. A large *Equisetum* from the Hawkesbury Sandstone, 445.—R. Etheridge, Jun., and J. Mitchell. On the Identity of *Bronteus Partschi*, De Koninck (*non* Barrande), from the Upper Silurian Rocks of New South Wales, 501.

——. Royal Society of New South Wales. Journal and Proceedings. Vol. xxiii. Part 2. 1889.

G. H. Mingaye. Notes on some New South Wales Minerals, 326.—E. C. Manfred. Notes on Goulburn Lime, 328.—W. A. Dixon. Well and River Waters of New South Wales, 465.

——. ——. ——. Vol. xxiv. Part 1. 1890.

Topeka. Kansas Academy of Science. Transactions of the 22nd and 23rd Meetings, 1889 & 1890. Vol. xii. 1890.

J. R. Mead. Notes on the Occurrence of Gold in Montana, 5.—R. Hay. Artesian Wells in Kansas, and the Causes of their Flow, 24.—E. H. S. Bailey. Some Kansas Mineral Waters, 25.—E. H. S. Bailey. On Barite and associated Minerals in the concretionary rocks of Eastern Kansas, 45.—O. C. Charlton. On the occurrence of Mammoth Remains in Franklin County, Kansas, 74.—R. Hay. Notes on some Kansas Salt Marsh, 97.—S. W. Williston. On the Structure of the Kansas Chalk,

100.—E. H. S. Bailey. "Feather Alum" from Colorado, 101.—S. W. Williston. A new Plesiosaur from the Niobrara Cretaceous of Kansas, 174.

Tokyo. College of Science, Imperial University. Journal. Vol. iii. Part 4. 1890.

Y. Kikuchi. On Cordierite as Contact Mineral, 312.

——. Imperial University of Japan. (Teikoku Daigaku.) Calendar for the year 1889–90 (22nd and 23rd year of Meiji). 1889.

Toronto. Canadian Institute. Proceedings. Series 3. Vol. vii. Fasciculus No. 2. 1890.

A. Harvey. Geology of North-west Lake Superior, 218.—H. R. Wood. Kaministquia Silver-bearing Belt, 245.

——. ——. Transactions. Vol. i. Parts 1 & 2. 1890 and 1891.

P. H. Bryce. Natural History of Ground Waters, 149.—A. Harvey. *Pelotechthen balanoides*, 213.—L. J. Clark. Formation of Toronto Island, 239.

Truro. Royal Cornwall Polytechnic Society. 58th Annual Report. 1890. 1891.

——. Royal Institution of Cornwall. Journal. Vol. x. Parts 1 & 2. 1890.

J. H. Collins. On the Origin and Development of Ore Deposits in the West of England, 109.—T. Clark. Mineralogy of the North-eastern Portion of the Lizard District, 176.—T. Clark. Notes on the Lizard Rocks, 393.—H. Crowther. The Pozo Pictorial Inscribed Stone, 403.

Turin. Reale Accademia delle Scienze. Atti. Vol. xxv. Disp. 11–15 *a*. 1889–90.

Piolti. I minerali del gneiss di Borgone (Val di Susa), 631.—F. Virgilio. Il Permo-carbonifero di Valle Stretta (alta valle della Dora Riparia), 715.

——. ——. ——. Vol. xxvi. Disp. 1–8. 1890–91. 1891.

C. Mylius. Intorno ad alcune forme inedite de Molluschi miocenici dei colli torinesi, rinvenute a S. Margherita, 453.

——. ——. Memorie. Serie 2. Tomo xl. 1890.

L. Bellardi e F. Sacco. I Molluschi terreni terziarii del Piemonte e della Liguria, 295, 469.

——. ——. Osservazioni Meteorologiche fatte nell' anno 1889 all' Osservatorio della R. Università. 1890.

——. ——. —— 1890 all' Osservatorio della R. Università. 1891.

Vienna. Beiträge zur Paläontologie Oesterreich-Ungarns und des Orients. Band viii. Hefte 1 bis 3. 1890. *Purchased.*

M. Schlosser. Die Affen, Lemuren, Chiropteren, Insectivoren, Marsurpialier, Creodonten, und Carnivoren des europäischen Tertiärs und

deren Beziehungen zu ihren aussereuropäischen Verwandten, 1.—A. Weithofer. Die fossilen Proboscidier des Arnothales in Toskana, 107.

Vienna. Beiträge zur Paläontologie Oesterreich-Ungarns und des Orients. Band viii. Heft 4. 1891. *Purchased.*

F. Wähner. Beiträge zur Kenntniss der tieferen Zonen des unteren Lias in den nordöstlichen Alpen, 241.

——. Kaiserliche Akademie der Wissenschaften. Anzeiger. 1890. Nos. 12–18, 25–27. 1890.

F. Toula. Geologische Beobachtungen an der unteren Donau, 114.—G. Bukowski. Reisebericht aus Kleinasien, 124, 161, 192.—A. Weithofer und A. Rodler. Die Wiederkäuer der Fauna von Maragha, 154.—A. Schrauf. Ueber Metacinnaberit von Idria, 156.—H. Reusch. Ueber sehr alte Gletscherbildungen, 251.

——. ——. ——. 1891. Nos. 1–7. 1891.

A. Rosiwal. Ueber Gesteine aus Ostafrika, 1.—G. Tschermak. Ueber die Chloritgruppe, 36.—C. Freih. v. Ettingshausen. Ueber tertiäre Fagus-Arten der südlichen Hemisphäre, 49.

——. ——. Denkschriften. Mathematisch-naturwissenschaftliche Classe. Band lvi.

*Zweite Abtheilung.*

A. Rodler. Ueber *Urmiatherium Polaki*, einen neuen Sivatheriiden aus dem Knockenfelde von Maragha, 313.

——. ——. Sitzungsberichte. Mathematisch-naturwissenschaftliche Classe. Band xcviii. Abth. 1. Hefte 1–7. 1889.

E. Jüssen. Ueber pliocäne Korallen von der Insel Rhodus, 13.—V. Hilber. Geologische Küstenforschungen zwischen Grado und Pola am adriatischen Meere, nebst Mittheilungen über ufernahe Baureste, 278.—V. v. Zepharovich. Ueber Vincinalflächen an Adular-Zwillingen nach dem Baveno-Gesetze, 404.—J. v. Siemiradski. Ueber Dislocationserscheinungen in Polen und den angrenzenden ausserkarpathischen Gebieten, 420.—N. Karakasch. Ueber einige Neocomablagerungen in der Krim, 428.—V. Hilber. Erratische Gesteine des galizischen Diluviums, 609.—G. Bukowski. Der geologische Bau der Insel Kasos, 657.

——. ——. ——. ——. Band xcviii. Abth. 1. Hefte 8–10. 1890.

V. Uhlig. Vorläufiger Bericht über eine geologische Reise in das Gebiet der goldenen Bistritz (nordöstliche Karpathen), 728.—K. A. Weithofer. Ueber Jura und Kreide aus dem nordwestlichen Persien, 56.

——. K.-k. Bergakademie zu Leoben und Přibram und die koeniglich-ungarische Bergakademie zu Schemnitz. Berg- und Hüttenmännisches Jahrbuch. Band xxxvii. Hefte 2–4. 1890.

J. Schardinger. Das Braunkohlen-Bergrevier von Elbogen-Karlsbad, 245.—E. Priwoznik. Mittheilungen über die im Laboratorium des k. k General-Probiramtes in Wien in den Jahren 1888 und 1889 ausgeführten Analysen und anderweitigen Untersuchungen, 393.

——. ——. ——. Band xxxix. Heft 1. 1891.

Vienna. Kaiserlich-koenigliche geologische Reichsanstalt. Abhandlungen. Band xiv. 1890.

A. Bittner. Brachiopoden den Alpen Trias, 1.

——. ——. ——. Band xv. Heft 3. 1891.

F. Teller. Ueber den Schädel eines fossilen Dipnoërs *Ceratodus Sturii*, nov. spec., aus Schichten der oberen Trias der Nordalpen, 1.

——. ——. Jahrbuch. 1889. Band xl. Hefte 1 u. 2. 1890.

J. Blaas. Erläuterungen zur geologischen Karte der diluvialen Ablagerungen in der Umgebungen Innsbruck, 21.—Hj. Sjögren. Ueber das diluviale, aralokaspische Meer und die nordeuropäische Vereisung, 51.—F. v. Sandberger. Ueber Steinkohlenformation und Rothliegendes im Schwarzwald und deren Floren, 77.—C. F. v. Camerlander. Geologische Aufnahmen in den mährisch-schlesischen Sudeten, 103.—J. M. Clements. Die Gesteine des Duppauer Gebirges in Nord Böhmen, 317.—C. v. John und H. B. v. Foullon. Chemische Untersuchungen der vier Trinkquellen von Luhatschowitz in Mähren, 351.—E. Jüssen. Beiträge zur Kenntniss der Klausschichten in den Nordalpen, 381.—M. M. Draghicénu. Erläuterungen zur geologischen Uebersichtskarte des Koenigreiches Rumänien, 399.—H. B. Foullon. Ueber die Darstellung und die Krystallform einiger Calciumchromate, 421.

——. ——. Verhandlungen, 1890. Nos. 6–18. 1890.

A Hoffmann. Millerit und Texasit aus dem Olivinfels vom Sommergraben bei Kraubat, 117.—G. Stache. Die Silurfaunen der Ostalpen, 121.—R. Hoernes. Versteinerungen aus dem miocänen Tegel von Waldersdorf, 129.—M. Vacek. Einige Bemerkungen über die Radstädter Tauern, 131.—A. Bittner. Ueber die Lagerungsverhältnisse am Nordrande der Tertiärbucht von Tüffer, 136.—H. B. v. Foullon. Chemische Analyse der vier Trinkquellen von Luhatschowitz, 145.—C. F. v. Camerlander. Die Haupttypen der krystallinischen Schiefer der Hohen Gesenkes, 146.—J. Niedzwiedzki. Neuvorkomnisse von Mineralien, 149.—A. Bittner. Eine triadische Conularia, 177.—R. Hoernes. Ueber die Pleurotomen des Wiener Tertiärbeckens, 178.—K. A. Weithofer. Ueber Tithon und Neocom der Krim, 195.—C. M. Paul. Reisebericht aus Mähren, 213.—E. Tietze. Die Gegend zwischen Mährisch-Trübau und Boskowitz, 225.—C. v. Camerlander. Das Gneissgebiet des nordwestlichen Mährens, 229.—J. Böhm. Flysch des Fürberges, Sulzberges, Teissenberges und von Muntigl mit den Nierentalschichten, 241.—R. Hoernes. Zur Geologie Untersteiermarks, 243.—L. C. Moser. Vorkommen von Mercur bei Mance, 249.—H. Lecheitner. Eine eigenthümliche Ausbildung der Gosauformation in Brandenberg, 250.—R. Hoernes. Das Vorkommen der Gattung *Surcula* in den Miocän-Ablagerungen der österr.-ungar. Monarchie, 261.—M. Raciborski. Ueber eine fossile Flora in der Tatra, 263.—M. Raciborski. *Taonurus ultimus* in Galizien, 265.—V. Hilber. Erwiederung (Thalungleichseitigkeit), 266.—A. Pichler. Zur Geognosie von Tirol, 268.—A. Bittner. Zur Geologie des Kaisergebirges, 268.—G. Geyer. Die tektonische Fortsetzung der Niederen Tauern, 268.—J. v. Siemiradzki. Ueber den oberen Jura in Polen und dessen Cephalopoden-Faunen, 279.—E. Tietze. Ungleichseitigkeit der Thäler, 282.—A. Bittner. Die sarmatischen und vorsarmatischen Ablagerungen der Tertiärbucht von Tüffer-Sagor, 283.—J. N. Woldřich. Ueber die diluviale Fauna der Höhlen bei Beraun in Böhmen, 290.—V. Uhlig. Vorlage des Kartenblattes Göding-Lundenburg, 292.—R. Hoernes. Das Vorkommen der Gattung *Genota* im oesterreichisch-ungarischen Miocän, 297.—J. N. Woldřich. *Arctomys*

*primigenius* aus Böhmen, 299.—A. Bittner. Aus dem Gebiete des Hochschwab und der nördlich angrenzenden Gebirgsketten, 299.—A. Bittner. Einsendung von Gesteinen aus dem südöstlichen Bosnien und aus dem Gebiete von Novibazar, 311.—E. Tietze. Neuere Beobachtungen in der Umgebung von Krakau, 316.—H. B. v. Foullon. Antimonit und Schwefel von Allchar in Macedonien, 318.—G. Bukowski. Geologische Aufnahmen in dem krystallinischen Gebiete von Mährisch-Schönberg, 322.

Vienna. Kaiserlich-koenigliche geologische Reichsanstalt. Verhandlungen, 1891. Nos. 1–7. 1891.

D. Stur. Jahresbericht 1890, 1.—R. Hoernes. Zur Geologie Untersteiermarks, 33.—L. v. Tausch. Bericht an die Direction der k. k. geol. Reichsanstalt über eine aus dem Fonde der Schloenbach-Stiftung subventionirte Studienreise nach Süd-deutschland, 35.—Kramberger-Gorjanovic. Die präpontischen Bildungen des Agramer Gebirges, 40.—C. M. Paul. Geologische Aufnahmen in Mähren, 41.—M. Vacek. Die geologische Verhältnisse des Grazer Beckens, 41.—A. Bittner. Triasbrachiopoden von der Raxalpe und von Wildangergebirge bei Hall in Tirol, 55.—E. Tietze. Die weissen Mergel des Agramer Gebirges, 60.—C. v. John. Natürliches Vorkommen von Humussäure in dem Falkenauer Kohlenbecken, 64.—C. v. John. Ueber die chemische Zusammensetzung des Taraspits und der Miemite ueberhaupt, 67.—G. Stache. Geologische Verhältnisse und Karte der Umgebung von Triest, 70.—L. v. Tausch. Ueber Conchodus aus der nordalpinen Trias, 75.—F. v. Sandberger. Nachträgliche Bemerkungen zur Abhandlung "Ueber Steinkohlenformation und Rothliegendes im Schwarzwald," 83.—S. Kontkiewicz. Brauner Jura in Russisch-Polen, 85.—J. Ploner. Die Moräne an Kitzbühel, 89.—V. Uhlig. Ueber einige Lias-Brachiopoden aus der Provinz Belluno, 91.—C. O. Cech. Die Tropfsteingrotte Samograd in Kroatien, 92.—V. Uhlig. Ueber den pieninischen Klippenzug, 94.—M. Raciborski. Zur Frage über das Alter des Karniowicer Kalkes, 98.—J. Prochazka. Ein Beitrag zur Kenntniss der Fauna des Miocängebietes der Umgebung von Mährisch-Trübau, 100.—F. Zeller. Ueber *Ceratodus Sturii*, n. sp., aus der oberen Trias der Nordalpen, 107.—G. Geyer. Bericht ueber die geologischen Aufnahmen im Gebiete des Specialkartenblattes Murau, 108.—R. Hoernes. Das Vorkommen der Gattung *Clavatula*, Lamk., in den marinen Miocänablagerungen Oesterreich-Ungarns, 125.—A. Bittner. Ueber *Parobrissus* und einige andere alttertiäre Echiniden-Gattungen, 133.—R. Hoernes. Die Gasteropoden der Meeresablagerungen der miocänen Mediterranstufe, 144.—H. B. von Foullon. Zur Geologie einiger Nickelerzlagerstätten, 149.—E. Tietze. Ueber das Alter des Karniowicer Kalkes, 153.—J. v. Siemiradzki. Ueber das Jura- und Rhät-Gebiet am Nordost-Abhange des polnischen Mittelgebirges, 163.—E. Tietze. Die Ergebnisse zweier Bohrungen in der Nähe von Wieliczka, 167.—C. F. v. Camerlander. Geologische Aufnahmen im Gebiete des Spieglitzer Schneeberges, 168.

——. Kaiserlich-koeniglich naturhistorisches Hofmuseum. Annalen. Band v. Nos. 2–4. 1890.

F. Koerber. Ueber das Meteor vom 15 October, 1889, 463.—A. Brezina. Ueber die Krystallform des Uranthallit, 495.

——. Kaiserlich-koenigliche zoologisch-botanische Gesellschaft. Verhandlungen. 1890. Band xl. Quartal 2–4. 1890.

Vienna. Tschermak's Mineralogische und Petrographische Mittheilungen. Neue Folge. Band xi. Hefte 4–6. 1890. *Purchased.*

J. Gränzer. Das orthoklasähnliche Druzenmineral und der Leucittephrit vom Eulenberge bei Leitmeritz, 277.—E. Ludwig. Der Preblauer Säuerling, 295.—E. Ludwig. Fortgesetzte Untersuchungen über die arsenhaltigen Vitriolquellen von Srebrenica in Bosnien, 301.—E. Ludwig. Die Mineralquellen des Büdös (Bálvnáyos) in Siebenbürgen, 304.—C. Doelter. Einige Versuche über die Löslichkeit der Mineralien, 319.—A. Pelikan. Natürliche Aetzung an Topaskrystallen von San Luis Potosi in Mexico, 331.—F. Becke. Aetzversuche am Fluorit, 349.—M. Hunter und H. Rosenbusch. Ueber Monchiquit, 445.—O. Lang. Ueber die Individualität der Gesteine, 467.—C. v. Than. Die chemische Constitution der Mineralwässer und die Vergleichung derselben, 487.—F. Becke. Orientirung des Dolomit von Gebroulaz, 536.

——. ——. ——. Band xii. Heft 1. 1891. *Purchased.*

J. J. Sederholm. Ueber die finnländischen Rapakiwigesteine, 1.—E. Ludwig und G. Tschermak. Neue Chloritanalysen, 32.—J. Hof. Keramohalit von Tenerifa, 39.—F. Becke. Krystallform und optische Orientirung des Keramohalit von Tenerifa, 45.—H. Rosenbusch. Zur Auffassung der chemischen Natur des Grundgebirges, 49.—A. Brunlechner. Der Baryt des Huttenberger Erzberges, 62.—G. Linck. Aetzfiguren am Sylvin, 82.

Warwick. Warwickshire Naturalists' and Archæologists' Field-Club. 34th Annual Report, 1889.

P. B. Brodie. On the Character, Variety, and Distribution of the Fossil Insects in the Palæozoic (Primary), Mesozoic (Secondary), and Cainozoic (Tertiary) Periods: with an account of the more recent discoveries in this branch of Palæontology up to the present day, 7.—W. Andrews. On the Bore-holes at Coventry, 27.

——. ——. 35th Annual Report, 1890. 1891.

P. B. Brodie. Annual Address of the President, 3.—W. Andrews. On a Discovery of Blue Slate in North Warwickshire, 9.—P. B. Brodie. On Fossil and Recent Extinct Birds, with an account of the Formations in which they occur, and the Circumstances of their Preservation, 11.

Washington. Smithsonian Institution. Annual Report for the year ending June 30, 1886. 1889.

——. ——. Annual Report for the year ending June 30, 1887. Parts 1 & 2. 1889.

——. ——. Annual Report of the Board of Regents, showing the operations, expenditures, and conditions of the Institution to July 1888. 1890.

——. ——. —— for the year ending June 30, 1888. Report of the U.S. National Museum. 1890.

——. ——. Contributions to Knowledge. Vol. xxvi. 4to. 1890.

A. Hyatt. Genesis of the Arietidæ, Article II. (1889.)

Washington. Smithsonian Institution. United States National Museum. Bulletin. No. 38. 1890.

——. ——. ——. Proceedings. Vol. xii. 1889. 1890.

C. D. Walcott. Descriptive Notes on new Genera and Species from the Lower Cambrian or *Olenellus* Zone of North America, 33.—C. D. Walcott. Description of a new Genus and Species of Inarticulate Brachiopod from the Trenton Limestone, 365.—T. Wilson. The Palæolithic Period in the District of Columbia, 371.—G. P. Merrill. Notes on the Serpentinous Rocks of Essex County, New York, 594.

Wellington. New Zealand Institute. Transactions and Proceedings. 1889. Vol. xxii. 1889. 1890.

J. Meeson. The newly opened Cave near Sumner, 64.—W. G. Mair. On the Disappearance of the Moa, 70.—F. W. Hutton. On the Relative Ages of the New Zealand Coalfields, 377.—F. W. Hutton. Note on the Geology of the Country about Lyell, 387.—J. Park. On the Conformable Relations of the Different Members of the Waitemata Series, 391. —H. P. Washbourne. A Theory on the Formation of Gold into Specks and Nuggets, 400.—J. Hardcastle. Origin of the Loess Deposit of the Timaru Plateau, 406.—A. McKay. On certain rare Minerals associated with the Tin Ore of Stewart Island, 415.—H. Hill. Descriptive Geology of the District between Napier and Ruapehu Mountain *viâ* Kuripapanga and Erehwon, 422.—H. Hill. Artesian Wells, 429.

Wiesbaden. Nassauischer Verein für Naturkunde. Jahrbücher. Jahrgang xliii. 1890.

R. Fresenius. Die Thermalquellen Wiesbaden sin chemischer Beziehung, 17.—A. von Reinach. Das Bohrloch in neuen wiesbadener Schlachthause, 33.

Yokohama. Seismological Society of Japan. Transactions. Vol. xiii. Part 2. 1890.

S. Sekiya and Y. Kikuchi. The Eruption of Bandai-San, 1.—C. G. Knott and C. M. Smith. Notes on Bandai-San, 223.

——. ——. ——. Vol. xv. 1890.

W. B. Mason. Times of Occurrence of Earthquakes at Telegraph Stations in Central Japan, 31.—C. G. Knott. M. de Ballore's Calculations on Earthquake Frequency, 41.—O. Otsuka. The Kumamoto Earthquake of July 28th, 1889, 47.—J. E. Pereira. Earthquakes felt in Yokohama, 63.—W. G. Forster. Earthquake Origin, 73.—J. Milne. Diagrams of Earthquakes recorded at the Chiri-kyoku in Tokyo, 93.—J. Milne. Report on Earthquake Observations made at the Chiri-kyoku during the year 1887, 99.—J. Milne. Catalogue of Earthquakes, February 1887 to April 1890, 127.—J. Milne. Earthquakes in connection with Electric and Magnetic Phenomena, 135.—Construction in Earthquake Countries, 163.

York. Yorkshire Philosophical Society. Annual Report for 1890. 1891.

J. W. Gregory. A Catalogue of the Pliocene Echinoidea in the Reed Collection in the Museum of the Yorkshire Philosophical Society, 37.—H. M. Platnauer. List of Figured Specimens in York Museum, 56.

## 2. Books.

*Names of Donors in Italics.*

*Abella y Casariego, E.* Descripcion Física, Geológica y Minera en bosquejo de la Isla de Panay. 8vo. Manila, 1890.

*Alford, C. J.* Geological Features of the Transvaal, South Africa. 8vo. London, 1891.

Alsace-Lorraine. Abhandlungen zur geologischen Specialkarte von Elsass-Lothringen. Band iii. Heft 5. 1889. *Purchased.*

*Ami, H. M.* On the Geology of Quebec and environs. 8vo. Rochester (N.Y.), 1891.

Ammon, L. von. Die permischen Amphibien der Rheinpfalz. 4to. Munich, 1889. *Purchased.*

*Anderson, A. A.* Terra. 2nd edition. 8vo. London, 1890.

*Antrobus, J. C., and Hatch, F. H.* Preliminary Note on the Composition and Origin of Cheshire Boulders.

*Army Medical Department.* Report for the year 1888. Vol. xxx. 1890.

Ayres, E. F. See *Chatard, T. M.*

Baden. Ministerium des Innern. Mittheilungen der Grossherzoglich Badischen Geologischen Landesanstalt. Band i. Erste Hälfte. 8vo. Heidelberg, 1890. *Purchased.*

——. ——. ——. Band i. Zweite Hälfte. 8vo. Heidelberg, 1891. *Purchased.*

——. ——. ——. Band ii. Erstes Heft. 8vo. Heidelberg, 1890. *Purchased.*

Bailey, G. See *Sherborn, C. Davies.*

*Bayley, W. S.* A Summary of Progress in Mineralogy and Petrography in 1889. 8vo. Waterville, Me., 1890.

——. —— 1890. 8vo. Waterville, Me., 1891.

*Beecher, C. E.* Development of the Brachiopoda. Part I. 8vo. New Haven (Conn.), 1891.

*Bell, R.* On Glacial Phenomena in Canada. 8vo. Washington, 1890.

——. The Nickel and Copper Deposits of Sudbury District, Canada. With an Appendix on the Silicified Glass-Breccia of Vermilion River, Sudbury District, by G. H. Williams. 8vo. Rochester (N.Y.), 1891.

*Beveridge, H.* Annual Address to the Asiatic Society of Bengal. 8vo. Calcutta, 1891.

*Bigot, A.* L'Archéen et le Cambrien dans le nord du massif Breton, et leurs équivalents dans le Pays de Galles. 8vo. Cherbourg, 1890.

——. Note sur quelques Pélécypodes des grès siluriens de l'Ouest de la France. 8vo. Paris, 1890.

——. Notice nécrologique sur M. Eugène-Eudes Deslongchamps. 8vo. Paris, 1890.

——. *See* SERIALS, Caen. Faculté des Sciences.

*Blake, J. F.* On the Inefficiency of Natural Selection for the Origin of Species. 8vo. London, 1890.

Blake, J. H. *See* England and Wales, *Geological Survey.*

*Bonney, T. G.* On the Crystalline Schists and their Relation to the Mesozoic Rocks in the Lepontine Alps. 8vo. London, 1890.

*Boyd, R. N.* Presidential Address to the Civil and Mechanical Engineers' Society, Session 1890–91. 8vo. London, 1890.

Braye, John. Swanage (Isle of Purbeck): Its History, Resources as an Invigorating Health Resort, Botany, and Geology. 8vo. London, 1890. *Presented by H. B. Woodward, Esq., F.G.S.*

*Briart, A.* Note sur les mouvements parallèles des roches stratifiées. 8vo. Liége, 1890.

——. Note sur une Faune Marine Landénienne dans l'Entre-Sambre-et-Meuse. 8vo. Liége, 1891.

British Museum (Natural History). A Guide to the Exhibition Galleries of the Department of Geology and Palæontology in the British Museum (Natural History). Parts i. & ii. 8vo. London, 1890. *Presented by the Trustees.*

——. Catalogue of the Fossil Reptilia and Amphibia in the British Museum (Natural History). Part iv., by R. Lydekker. 8vo. London, 1890. *Presented by the Trustees.*

——. Catalogue of the Fossil Cephalopoda in the British Museum (Natural History). Part ii., by A. H. Foord. 8vo. London, 1891. *Presented by the Trustees.*

——. Catalogue of the Fossil Birds, by R. Lydekker. 8vo. London, 1891. *Presented by the Trustees.*

——. Catalogue of the Fossil Fishes. Part ii., by A. Smith Woodward. 8vo. London, 1891. *Presented by the Trustees.*

*Brockbank, W.* Notes on the Discovery of *Estheria minuta*, var. *Brodieana*, at Alderley Edge. 8vo. Manchester, 1891.

——. On the Entomostraca and Annelida in the Levenshulme Mottled Limestones. 8vo. Manchester, 1891.

*Brodie, P. B.* On Fossil and Recent Extinct Birds. 8vo. Warwick, 1890.

*Brongniart, C.* Sur un nouveau Poisson fossile du terrain houiller de Commentry (Allier), *Pleuracanthus Gaudryi.* 8vo. Paris, 1888.

——. Insectes. (Extrait de l'Annuaire Géologique Universel.) Tome v. 1888. 8vo. Paris, 1889.

——. Michel-Eugène Chevreul. 8vo. Paris, 1889.

——. Les Blattes de l'époque houillère. 4to.

*Brown, H. Y. L.* A Record of the Mines of South Australia. 8vo. Adelaide, 1890.

——. ——. ——. *Presented by D. D. Rosewarne, Esq., F.G.S., Inspector of Mines for the Government of South Australia.*

——. *See* South Australia.

*Browne, M.* Revision of a Genus of Fossil Fishes, *Dapedius.* 8vo. Leicester, 1890.

Buckler, W. The Larvæ of the British Butterflies and Moths. Vol. iv. 8vo. London, 1891. (*Ray Society.*)

*Buckman, S. S.* The Sections exposed between Andoversford and Chedworth. 8vo. Gloucester, 1890.

*Burrows, H. W.* See *Sherborn, C. Davies.*

*Burrows, H. W., C. Davies Sherborn,* and *G. Bailey.* The Foraminifera of the Red Chalk of Yorkshire, Norfolk, and Lincolnshire. 8vo. London, 1890.

California State Mining Bureau. W. Irelan, Jr., State Mineralogist. 10th Annual Report of the State Mineralogist for the year ending December 1, 1890. 8vo. Sacramento, 1890. With Atlas of Maps, 8vo.

Cameron, P. A Monograph of the British Phytophagous Hymenoptera. 8vo. London, 1890. (*Ray Society.*)

Canada. *Geological and Natural History Survey.* Annual Report. (New Series.) Vol. iii. Part 1. 1887–88. 8vo. Montreal, 1889.

——. ——. Maps &c. (New Series.) Vol. iii. Nos. 2, 3, 4, 9, 11, 13, 14. 8vo. Montreal, 1889.

Canada. *Geological and Natural History Survey.* Catalogue of Canadian Plants. Part 5. Acrogens, by J. Macoun. 8vo. Montreal, 1890.

——. ——. List of Canadian Hepaticæ, by W. H. Pearson. 8vo. Montreal, 1890.

——. ——. Contributions to Canadian Palæontology. Vol. i. Part 3, by J. F. Whiteaves. 8vo. Montreal, 1891.

——. ——. Contributions to Canadian Palæontology. Vol. iii. I. On Vertebrata from the Tertiary and Cretaceous Rocks of the North-West Territory, by E. D. Cope. 4to. Montreal, 1891.

——. ——. (Geological Survey Department.) Summary Report for the year 1890. 8vo. Ottawa, 1891.

*Capellini, G.* Zifioidi fossili e il rostro di Dioplodonte della Farnesina presso Roma. 4to. Bologna, 1891.

*Carez, L.* Revue annuelle de Géologie. 4to. Paris, 1890.

——. Géologie—France. [Extrait de l'Annuaire Géologique Universel.] 8vo. Paris, 1891.

——. Géologie—Iles Britanniques. 1889. [Extrait de l'Annuaire Géologique Universel.] 8vo. Paris, 1891.

——. Géologie—Système Jurassique. 1889. [Extrait de l'Annuaire Géologique Universel.] 8vo. Paris, 1891.

*Cayeux, L.* Coup-d'œil sur la composition du crétacé des environs de Péronne. 8vo. Lille, 1890.

——. Etude micrographique de la Craie des environs de Lille. 8vo. Lille, 1890.

——. Forage de la ville d'Hazebrouck. Nouveaux documents sur la faune de l'Argile des Flandres. 8vo. Lille, 1890.

*Charlesworth, E.* On the enigmatical Flint Bodies bearing the name Paramoudra, and which are only known in the Chalk of Norfolk and the Chalk of Antrim. 8vo. London, 1891.

*Chatard, T. M.* Natural Soda, its Occurrence and Utilization. 8vo. Washington (D. C.), 1888.

——. Urao; with notes on the crystallization of Trona (Urao). By E. F. Ayres. 8vo. New Haven (Conn.), 1889.

*Clarke, F. W., and E. A. Schneider.* Experiments upon the Constitution of the Natural Silicates. 8vo. New Haven (Conn.), 1890.

——. Experimentaluntersuchung über die Constitution der natürlichen Silicate. 8vo. Leipzig, 1890.

*Clarke, J. M.* As Trilobitas do Grez de Ereré e Maccurú, estado do Pará, Brazil. 4to. Rio de Janeiro, 1890.

Clarke, J. W., and T. McKenny Hughes. The Life and Letters of the Reverend Adam Sedgwick. Vols. i. & ii. 8vo. Cambridge, 1890. *Presented by the Syndics of the Cambridge University Press.*

*Claypole, E. W.* Palæontological Notes from Indianapolis. 8vo. Minneapolis, 1890.

*Collin, J. H.* On the Origin and Development of Ore Deposits in the West of England. 8vo. Truro, 1890.

*Congrès Géologique International.* Compte-rendu de la 4e Session, Londres, 1888. 8vo. London, 1891.

*Conwentz, H.* Monographie der baltischen Bernsteinbäume. 4to. Danzig, 1890.

——. Ueber die Verbreitung des Succinits, besonders in Schweden und Dänemark. 8vo. Danzig, 1890.

Cope, E. D. *See* Canada.

*Cotteau, G.* (Paléontologie Française.) Terrains Tertiaires: Éocène, Échinides. Tome ii. Livr. 18–20. 8vo. Paris, 1889–90.

——. Congrès Scientifique. Les sciences naturelles à la Réunion des Délégués des Sociétés Savantes. 8vo. Auxerre, 1889.

——. Description de trois Échinides vivants recueillis par le Dr. J. Jullien sur les côtes de Guinée (Libéria). 8vo. Paris, 1889.

——. Échinides recueillis dans la province d'Aragon (Espagne) par M. Maurice Gourdon. 8vo. Paris, 1889.

——. Échinides recueillis par M. Jullien sur les côtes de Guinée. 8vo. Paris, 1889.

——. Échinides nouveaux ou peu connus. 2e Série. viiie fascicule. 8vo. Paris, 1890.

——. Note sur quelques Échinides du terrain crétacé du Mexique. 8vo. Paris, 1890.

——. La Géologie à l'Exposition Universelle et dans les Congrès Internationaux de 1889. 8vo. Auxerre, 1890.

——. Sur les Échinides crétacés du Mexique. 4to. Paris, 1890.

*Credner, H.* Die Stegocephalen und Saurier aus dem Rothliegenden des Plauen'schen Grundes, bei Dresden. IX. Theil. 8vo. Berlin, 1890.

——. Die Urvierfüssler (Eotetrapoda) des sächsischen Rothliegenden. 8vo. Berlin, 1891.

Creed, H. K. On the Standing Stones in Mutford Wood. 8vo. Beccles, 1872. *Presented by W. Whitaker, Esq., F.R.S., F.G.S.*

*Crick, G. C.* *See* Foord, A. H.

Dallas, W. S. See *Woodward, H.*

*Dalton, W. H.* A List of Works referring to British Mineral and Thermal Waters. 8vo. London, 1889.

*Dames, W.* *Anarosaurus pumilio*, nov. gen. nov. sp. 8vo. Berlin, 1890.

——. Ueber Vogelreste aus Saltholmskalk von Limhamn bei Malmö. 8vo. Stockholm, 1890.

——. Ueber die Schichtenfolge der Silurbildungen Gotlands und ihre Beziehungen zu obersilurischen Geschieben Norddeutschlands. 8vo. Berlin, 1890.

*Dana, J. D.* On the Crystalline Limestone and conformably associated Taconic and other Schists of the Green Mountain Region. 8vo. New Haven (Conn.), 1873–88.

Dantzeuber, P. See *Dupont, E.*

*Daubrée, A.* Expériences sur les actions mécaniques exercées sur les roches par des gaz à hautes températures, doués de très fortes pressions et animés de mouvements très rapides. 4to. Paris, 1891.

——. Expériences sur les déformations que subit l'enveloppe solide d'un sphéroïde fluide, soumis à des efforts de contraction : applications possibles aux dislocations du globe terrestre. 4to. Paris, 1890.

*Davis, W. M.*, and S. W. Loper. Two Belts of Fossiliferous Black Shale in the Triassic Formation of Connecticut. 8vo. Rochester (N.Y.), 1891.

*Davis, W. Morris.* The Rivers of Northern New Jersey, with notes on the Classification of Rivers in general. 8vo. Washington (D.C.), 1890.

*Dawson, G. M.* Note on the Geological Structure of the Selkirk Range. 8vo. Rochester (N.Y.), 1891.

——. On the Glaciation of the Northern Part of the Cordillera, with an attempt to correlate the events of the Glacial Period in the Cordillera and the Great Plains. 8vo. Minneapolis, 1890.

——. On the Later Physiographical Geology of the Rocky Mountain Region in Canada, with special reference to changes in elevation and the history of the Glacial Period. 4to. Montreal, 1890.

*Dawson, Sir J. W.* On Fossil Plants from the Similkameen Valley and other places in the Southern Interior of British Columbia. 4to. Montreal, 1890.

Day, D. T. *See* United States Department of the Interior.

*Deane, G.* The Future of Geology. 8vo. Birmingham, 1890.

De la Beche, H. T. Handbuch der Geognosie. Nach der zweiten Auflage des engl. Originals bearbeitet von H. von Dechen. 8vo. Berlin, 1832. *Purchased.*

*Derby, O. A.* Nota sobre a geologia e paleontologia de Matto Grosso. 8vo. Rio de Janeiro, 1890.

——. As Trilobitas do Grez de Ereré e Maecurú, Estado do Pará, Brazil. 4to. Rio de Janeiro, 1890.

*Draghicénu, M.* Erläuterungen zur geologischen Uebersichtskarte des Koenigreiches Rumänien. 8vo. Vienna, 1890.

*Dru, L.* Projet de Canal entre le Don et le Volga. 4to. Paris, 1886.

Duncan, P. Martin. Memoir of the late Dr. 8vo. London, 1891. *Presented by J. E. Harting, Esq., F.L.S.*

*Dupont, E.* Notice sur Laurent-Guillaume de Koninck. 12mo. Brussels, 1891.

——, et P. Dantzeuber. Sur des Mollusques vivants et postpliocènes recueillis au cours d'un voyage au Congo en 1887. 8vo. Brussels, 1890.

*Ebert, T.* Ueber die Aufnahmen im Gebiete der Section Garnsee (Westpreussen). 8vo. Berlin, 1885.

——. *Tulotoma Degenhardtii*, Dunker und Ebert. 8vo. Berlin, 1885.

——. Ueber Aufnahme der Section Neuenberg. 8vo. Berlin, 1886.

——. *Teredo megotara*, Hanley, aus dem Septarienthon von Finkenwalde. 8vo. Berlin, 1887.

——. Beitrag zur Kenntniss der tertiären Decapoden Deutschlands. 8vo. Berlin, 1887.

——. Die Echiniden des Nord- und Mitteldeutschen Oligocäns. 4to. Berlin, 1889. Atlas, 4to.

——. Die Ranien des Kressenbergs. 8vo. Berlin, 1889.

——. Ueber die Art des Vorkommens und die Verbreitung von *Gervillia Murchisoni*, Geinitz, im Mittleren Buntsandstein. 8vo. Berlin, 1889.

——. *Prestwichia* (*Euproops*) *Scheelana*, n. sp. 8vo. Berlin, 1890.

England and Wales. *Geological Survey*. Memoirs. The Geology of the country around Ingleborough, with parts of Wensleydale and Wharfedale (Explanation of Quarter-sheet 97 S.W., New Series, Sheet 50), by J. R. Dakyns, R. H. Tiddeman, W. Gunn, and A. Strahan. 8vo. London, 1890.

——. ——. ——. The Pliocene Deposits of Britain, by C. Reid. 8vo. London, 1890.

——. ——. ——. The Geology of the neighbourhood of Flint, Mold, and Ruthin (Explanation of Quarter-sheet 79 S.E.), by A. Strahan, &c. 8vo. London, 1890.

——. ——. ——. The Geology of parts of North Lincolnshire and South Yorkshire (Explanation of Sheet 86), by W. A. E. Ussher, &c. 8vo. London, 1890.

——. ——. ——. The Geology of the country near Yarmouth and Lowestoft (Explanation of Sheet 67), by J. H. Blake. 8vo. London, 1890.

*Ettingshausen, C. Freiherr von.* Das australische Florenelement in Europa. 4to. Gratz, 1890.

——. Die fossile Flora von Schoenegg bei Wies in Steiermark. I. Theil. 4to. Vienna, 1890.

——. Das australische Florenelement in Europa. 4to. Gratz, 1890.

——, und F. Krašan. Untersuchungen über Ontogenie und Phylogenie der Pflanzen auf paläontologischer Grundlage. 8vo. Vienna, 1890.

——, ——. ——. 4to. Vienna, 1890.

*Evans, J. W.* The Geology of the North-east of Caithness, and a discussion as to the age of the Old Red Sandstone of the North of Scotland. 8vo. London, 1891.

*Eyerman, J.* Bibliography of North American Vertebrate Palæontology for the year 1889. 8vo. Minneapolis, 1890.

——. —— 1890. 8vo. Minneapolis, 1891.

*Favre, E., et H. Schardt.* Revue géologique Suisse pour l'année 1889. 8vo. Geneva, 1890.

Fawkes, J. W., and *J. Marcou.* On Excavations made in Rocks by Sea-Urchins. 8vo. Minneapolis, 1890.

*Felix, J.* Beiträge zur Kenntniss der Gattung *Protosphyræna*, Leidy. 8vo. Berlin, 1890.

Felix, J., and H. Lenk. Beiträge zur Geologie und Paläontologie der Republik Mexico. III. Theil. 4to. Stuttgart, 1891. *Purchased.*

*Fontaine, W. M.*, and *F. H. Knowlton.* Notes on Triassic Plants from New Mexico. 8vo. Washington, 1890.

*Foord, A. H.*, and *G. C. Crick.* Note on the Identity of *Nautilus neocomiensis*, Sharpe (*non* d'Orbigny), with *Nautilus Deslongchampsianus*, d'Orb. 8vo. London, 1891.

—— ——. A Revision of the Group of *Nautilus elegans*, J. Sowerby. 8vo. London. 1890.

Foord, A. H. *See* British Museum.

*Fordham, H. G.* A record of water-level in a deep chalk well at Odsey Grange, Royston, 1878–88. 8vo. Hertford, 1890.

*Fornasini, C.* Nota preliminare sui Foraminiferi della marna pliocenica del Ponticello di Savena nel Bolognese. 8vo. Rome, 1883.

——. Il *Nautilus obliquatus* di Batsch. 8vo. Rome, 1890.

Foshay, P. Max. Preglacial drainage and recent geological history of Western Pennsylvania. 8vo. New Haven (Conn.), 1890. *Presented by Dr. J. W. Spencer, F.G.S.*

Foster, C. Le Neve. The Progress of the Art of Mining. 4to. London, 1891.

*Foster, C. Le Neve.* *See* Great Britain. Home Department.

Fournier, E. Esquisse géologique des environs de Marseille. 8vo. Marseille, 1890. *Purchased.*

Fraas, E. Die Ichthyosaurier der süddeutschen Trias- und Jura-ablagerungen. 4to. Tübingen, 1891. *Purchased.*

France. *Ministère des Travaux Publics.* Études des Gîtes Minéraux de la France. Bassin houiller et permien d'Autun et d'Épinac. Fascicule II. Flore Fossile, Partie 1, par R. Zeiller. Texte et Atlas. 4to. Paris, 1890.

*Frazer, P.* The Persistence of Plant and Animal Life under changing conditions of environment. 8vo. Philadelphia, 1890.

——. The Philadelphia Meeting of the International Congress of Geologists. 8vo. Minneapolis, 1890.

——. The Progress of Chemical Theory ; its helps and hindrances 8vo. Philadelphia, 1891.

——. The Warrior Coal-field of Northern Alabama. 8vo. Minneapolis, 1891.

——. Descriptive Table of Elements. 8vo.

Fremy, E. Synthèse du Rubis. 1877–90. 4to. Paris, 1891. *Purchased.*

*Fritsch, A.* Fauna der Gaskohle und des Kalksteines der Permformation Böhmens. Band iii. Heft 4. 4to. Prague, 1890.

*Gagel, C.* Die Brachiopoden der cambrischen und silurischen Geschiebe im Diluvium der Provinzen Ost- und Westpreussen. 4to. Königsberg in Pr. 1890.

*Gaudry, A.* Les Enchaînements du Monde Animal dans les temps géologiques. Fossiles Secondaires. 8vo. Paris, 1890.

Geinitz, H. B. *See* SERIALS. Dresden.

*Gilbert, C. J.* The Geology of Sutton Coldfield. 8vo. Berkhampstead, 1890.

Godwin-Austen, H. H. Land and Freshwater Mollusca of India, including South Arabia, Baluchistan, Afghanistan, Kashmir, Nepal, Burmah, Pegu, Tenasserim, Malay Peninsula, Ceylon, and other islands of the Indian Ocean. Supplementary to Messrs. Theobald and Hanley's 'Conchologia Indica,' Parts 1–6. Text. 8vo. Plates 4to. London, 1882–88. *Presented by the Secretary of State for India.*

Goldschmidt, V. Index der Krystallformen der Mineralien. Band iii. Hefte 4–6. 1891. *Purchased.*

*Goodchild, J. G.* An Outline of the Geological History of Upper Swaledale. 8vo. Huddersfield, 1890.

——. Dolomitic Limestones. 8vo. Edinburgh, 1890.

——. Excursion to Edenside. 8vo. London, 1890.

——. Notes on Faults. 8vo. Edinburgh, 1890.

——. Notes on some Irregular Forms of Stratification. 8vo. Edinburgh, 1890.

——. Notes on some observed Rates of Weathering of Limestones. 8vo. London, 1890.

——. On some Abnormal Deposits of Limestone. 8vo. Edinburgh, 1890.

——. Some of the Birds observed in Upper Swaledale. 8vo. Huddersfield, 1890.

——. Some of the Flowering Plants and of the Ferns of Upper Swaledale. 8vo. Huddersfield, 1890.

——. The Paste of Limestones. 8vo. London, 1890.

——. The Motion of Land-ice. 8vo. London, 1891.

Goonetillcke, W. Panini's Eight Books of Grammatical Sūtras. Vol. i. Part 1. 8vo. Bombay, 1882. *Presented by the Ceylon Branch of the Royal Asiatic Society.*

*Gosselet, J.* Deux excursions dans le Hundsrück et le Taunus, 1890. 8vo. Brussels, 1890.

——. Étude sur les Travaux de Charles Lory. 8vo. Brussels, 1890.

Great Britain. Home Department. Mines. List of Mines worked in the year 1889. 4to. London, 1890. *Presented by Dr. C. Le Neve Foster, F.G.S.*

——. ——. ——. Report of *C. Le Neve Foster, Esq.*, H.M. Inspector of Mines for the North Wales, &c., and Isle-of-Man District (No. 9). 4to. London, 1889.

——. ——. ——. List of the Plans of Abandoned Mines deposited in the Home Office, under the Coal and Metalliferous Mines Regulation Acts, including Plans transferred from the late 'Mining Record' Office. Corrected to 31st December, 1880. 4to. London, 1891. *Presented by Dr. C. Le Neve Foster, F.G.S.*

——. ——. ——. Report of *A. H. Stokes*, H. M. Inspector of Mines for the Midland District (No. 8), to Her Majesty's Secretary of State. For the year 1889. 4to. London, 1890.

——. ——. ——. Mineral Statistics of the United Kingdom of Great Britain and Ireland, with the Isle of Man, for the year 1889. 4to. London, 1890. *Presented by the Secretary of State for the Home Department.*

——. ——. ——. Reports. 1890. Summaries of the Statistical Portion of the Reports of Her Majesty's Inspectors of Mines. 4to. London, 1891. *Presented by that Department.*

Green, A. H., L. C. Miall, T. E. Thorpe, A. W. Rücker, and — Marshall. Coal; its History and Uses. 8vo. London, 1878. *Purchased.*

*Green, W. L.* Notice of Prof. J. D. Dana's 'Characteristics of Volcanoes.' 8vo. Honolulu, 1890.

*Gregorio, Marquis Antoine de.* Annales de Géologie et de Paléontologie. Livr. 7ᵉ et 8ᵉ. 4to. Palermo, 1890.

*Gümbel, C. W. v.* Geologische Bemerkungen über die Thermen von Bormio und das Ortlergebirge. 8vo. Munich, 1889.

Gunn, John. Obituary Notice of. Slip. [Norwich] 1890. *Presented by Dr. H. Woodward, F.R.S.*

*Guppy, R. J. L.* On a Specimen of *Pleurotomaria* from Tobago. 8vo. ——?, 1891.

*Guppy, R. J. L.* On the Water-bearing Capacities of some of the Rock-formations of Trinidad. 8vo. Port of Spain ?, 1891.

——. Remarks on the Geological Position of the *Polycystina* Beds of South Naparima. 8vo. Trinidad ?, 1890.

*Haeusler, R.* Notes sur les Foraminifères de la zone à *Ammonites transversarius* du canton d'Argovie. 8vo. Lausanne, 1882.

——. Ueber die neue Foraminiferengattung *Thuramminopsis.* 8vo. Stuttgart, 1883.

——. Die Lituolidenfauna der aargauischen Impressaschichten. 8vo. Stuttgart, 1885.

——. Bemerkungen über einige liasische Milioliden. 8vo. Stuttgart, 1887.

——. Die Lageninen der schweizerischen Jura- und Kreideformation. 8vo. Stuttgart, 1887.

——. Notes sur quelques Foraminifères des marnes à bryozoaires du Valanginien de Ste. Croix. 8vo. Lausanne, 1887.

——. Monographie der Foraminiferen-Fauna der schweizerischen *Transversarius*-Zone. 4to. Zurich, 1890.

*Hall, Marshall.* Glacier Observations. 8vo. London, 1891.

*Hall, Townshend M.* Geology of Devonshire. 4to. ——, 1890.

*Hanks, H. G.* On certain Magnetic Rocks of Arizona and California. 8vo. San Francisco, 1890.

*Harada, T.* Die japanischen Inseln. Lieferung 1. 8vo. Berlin, 1890.

——. ——. ——. *Purchased.*

*Harker, A.* On the Sections in the Forest Marble and Great Oolite formations, exposed by the new railway from Cirencester to Chedworth. 8vo. Gloucester, 1891.

*Harrison, J. B.,* and *A. J. Jukes-Browne.* The Geology of Barbados. 8vo. 1890.

——. *See* MAPS.

*Hatch, F. H.* On the Lower Silurian Felsites of the South-east of Ireland. 8vo. London, 1889.

——. On some West Yorkshire Mica-trap Dykes. 8vo. London, 1890.

——. An Introduction to the Study of Petrology : The Igneous Rocks. 8vo. London, 1891.

——. ——. ——. *Purchased.*

*Hatch, F. H.* On the Occurrence of Soda-Felsites (Keratophyres) in Co. Wicklow, Ireland. 8vo. London, 1889.

——. *See* Antrobus, J. C., and Rosenbusch, H.

——. *See* Rosenbusch, H.

Hébert, Edmond. Obituary notices by M. Hermite, &c. 8vo. Paris, 1890. *Presented by Members of the 'Laboratoire de Géologie de la Sorbonne,'* &c.

*Hendy, J. B. C.* On a "Wash-out" found in the Pleasley and Teversall Collieries. 8vo. London, 1890.

*Hicks, H.* The succession in the Archæan Rocks of America compared with that in the Pre-Cambrian Rocks of Europe. 8vo. London, 1883.

*Hill, R. T.* The Comanche Series of the Texas-Arkansas Region. 8vo. Rochester (N.Y.), 1891.

Holmes, T. V. *See* Periodicals. London. Geologists' Association.

*Hopkinson, J.* On geological photography in Hertfordshire. 8vo. Hertford, 1890.

——. On local scientific investigation in connection with Committees of the British Association. 8vo. Hertford, 1890.

——. Schedule of subjects of local interest recommended for investigation by Provincial Scientific Societies. 8vo. Hertford, 1890.

Hughes, T. McK. *See* Clark, J. W.

*Hull, E.* Our Coal Resources (with Diagram). 8vo. Edinburgh, 1890.

——. Sketch of the Geological History of Egypt and the Nile Valley. 8vo. London, 1890.

*Hunter, R. C.* Porthcawl as a Health Resort. 8vo. Bristol, 1891.

*Hutton, F. W.* Oscillations of the Earth's Surface. 8vo. Melbourne, 1890.

*Hyland, J. S.* On some specimens from Wady Halfa, Upper Egypt. 8vo. Dublin, 1890.

India. *Geological Survey.* Memoirs. Vol. xxiv. Part 2. 1890.

——. ——. Records. Vol. xxiii. Parts 2–4. 1890.

Irelan, Jr., W. *See* California State Mining Bureau.

*Irving, A.* Note on the elevation of the Weald. 8vo. London, 1890.

Issel, A., e S. Squinabol. Note esplicative della Carta Geologica della Liguria e Territori Confinanti. $\frac{1}{200,000}$. 8vo. Genoa, 1891. With the Map. *Purchased.*

——. ——. Carta Geologica della Liguria. *See* BOOKS.

Italy. Ministero di Agricoltura, &c. Rivista del Servizio Minerario nel 1889. 8vo. Florence, 1890. *Presented by H. Bauerman, Esq., F.G.S.*

——. *R. Ufficio Geologico.* Memorie descrittive della Carta Geologica d'Italia. Vol. v. Descrizione geologica-mineraria della Zona Argentifera del Sarrabus (Sardegna) di C. de Castro. 8vo. Rome, 1890.

——. ——. ——. ——. Annessa. Carta geologico-mineraria del Sarrabus (Sardegna) nella scale di 1 a 50,000. 8vo. Rome, 1890.

——. ——. ——. Vol. vi. Osservazioni fatte nella Colonia Eritrea da L. Baldacci. 8vo. Rome, 1891.

*James, F. J.* On the Maquoketa Shales, and their correlation with the Cincinnati Group of South-western Ohio. 8vo. Minneapolis, 1890.

——. On variation: with special reference to palæozoic genera. 8vo. Minneapolis, 1889.

*Jervis, G. See* Revel, A.

*Jervis, Chev. W.* Della Relazione tra la Geologia e la Geografia Fisica. 8vo. Turin, 1882.

——. Progetto di Massima di Lavori Idraulici Nazionali nel Veneto. 8vo. Turin, 1884.

——. Delle cause dei Movimenti Tellurici e dei possibili ripari, con riguardo speciale al Terremoto Alpino dell' inverno dell' anno 1887. 8vo. Turin, 1887.

*Jones, T. Rupert.* Seventh Report of the Committee on the Fossil Phyllopoda of the Palæozoic Rocks. 8vo. London, 1889.

——. Eighth Report of the Committee on the Fossil Phyllopoda of the Palæozoic Rocks. 8vo. London, 1890.

——. Notes on the Palæozoic Bivalved Entomostraca. No. xxix. 8vo. London, 1890.

——. Obituary notice of William Kitchen Parker, F.R.S. (From 'Nature,' July 24, 1890.)

——. On some Devonian and Silurian Ostracoda from North America, France, and the Bosphorus. 8vo. London, 1890.

*Jones, T. Rupert.* On some *Estheriæ* and *Estheria*-like Shells from the Carboniferous Shales of Western Scotland. 8vo. Glasgow, 1890.

——. On some Fossil *Estheriæ.* 8vo. London, 1890.

——. On some Fossils from Central Africa. 8vo. London, 1890.

——. On some small Bivalve Shells from the Karoo Formation, South Africa. 8vo. London, 1890.

——. Obituary notice of Henry Bowman Brady. 8vo. London, 1891.

——. On some more Fossil Estheriæ. 8vo. London, 1891.

——. On the Utility of an Elementary Knowledge of Geology to the Officers of the Army and Navy. 8vo. London, 1891.

——, and J. E. H——. Obituary notice of William Kitchen Parker. 8vo. London, 1890.

——, and J. W. Kirkby. On the Ostracoda found in the Shales of the Upper Coal-measures at Slade Lane, near Manchester. 8vo. Manchester, 1891.

*Jordan, H. K.* On the species and varieties of the Genus *Fusus* which inhabit the seas surrounding the British Isles. 8vo. ——, 1890.

Jukes-Browne, A. J. The Building of the British Isles. 8vo. London, 1888. *Purchased.*

*Kokscharow, Nikolai v.* Materialien zur Mineralogie Russlands. Band x., pp. 225–352. 8vo. St. Petersburg, 1891.

Kováts, Julius von. *See* PERIODICALS. Pesth.

*Lacroix, A.* Sur les enclaves acides des roches volcaniques de l'Auvergne. 8vo. Paris, 1890.

*Lapparent, A. de.* De la mesure du temps par les phénomènes de sédimentation. 8vo. Paris, 1890.

——. Sur l'argile à silex du bassin de Paris. 8vo. Paris, 1891.

*Le Conte, J.* Elements of Geology. New edition. 8vo. New York, 1889. *Purchased.*

Lehmann, J. *See* SERIALS. Kiel.

Löfstrand, G. Om Apatitens Förekomstsatt i Norbottens Län jemfördt med des Upptradande i Norge. 8vo. Stockholm, 1890. *Presented by the Geological Survey of Sweden.*

Lommel, E. Georg Simon Ohm's wissenschaftliche Leistungen. 4to. Munich, 1889. *Presented by the K. bayerische Akademie der Wissenschaften.*

Loriol, P. de. *See* Portugal.

*Lossen, K. A.* Beiträge zur Beurtheilung der Frage nach einer einstigen Vergletscherung des Brocken-Gebietes. 8vo. Berlin, 1890.

——. Geognostische Beschreibung der linksrheinischen Fortsetzung des Taunus in der östlichen Hälfte des Kreises Kreuznach, nebst einleitenden Bemerkungen über das "Taunus-Gebirge" als geognostiches Ganzes. 8vo. Berlin, 1867.

——. Geologische und petrographische Beiträge, I. 8vo. Berlin, 1881.

——. Mittheilungen aus der Conferenz der Mitarbeiter der koeniglichen geologischen Landesanstalt über den Arbeitsplan für 1883. 8vo. Berlin, 1884.

——. Studien an metamorphischen Eruptiv- u. Sedimentgesteinen, erläutert an mikroskopischen Bildern. I. 8vo. Berlin, 1884.

——. ——. II. 8vo. Berlin, 1885.

——. Ueber die Anforderungen der Geologie an die petrographische Systematik. 8vo. Berlin, 1884.

——. Geologische und petrographische Beiträge zur Kenntniss des Harzes. 8vo. Berlin, 1886.

——. Vergleichende Studien über die Gesteine des Spiemonts und des Bosenbergs bei St. Wendel und verwandte benachbarte Eruptivtypen aus der Zeit des Rothliegenden. 8vo. Berlin, 1890.

——, und E. Beyrich. Erläuterungen zur geologischen Specialkarte von Preussen, Nos. 238, 239, 257, und Grad Abtheilung 56. Nos. 23, 24, 29, 30. 8vo. Berlin, 1870–83.

Lucas, J. Report on the prospect of finding Coal under the Estate of Over Norton, Oxfordshire. 8vo. London, 1891. *Presented by W. Whitaker, Esq., F.R.S., F.G.S.*

*Lydekker, R.* Catalogue of Fossil Mammals, Birds, Reptiles, and Amphibians in the Science and Art Department, Dublin. 8vo. Dublin, 1891.

——. On the generic identity of *Sceparnodon* and *Phascolonus*. 8vo. London, 1891.

Lydekker, R. *See* British Museum.

Macgregor, W. *See* Reports, Colonial. British New Guinea.

Macoun, J. *See* Canada.

*Marcou, J.* Jura, Neocomian, and Chalk of Arkansas. 8vo. Minneapolis, 1889.

*Marcou, J.* Reply to the questions of Mr. Selwyn on "Canadian geological classification for Quebec." 8vo. Boston, 1889.

——. The Mesozoic Series of New Mexico. 8vo. Minneapolis, 1889.

——. Genesis of the Arietidæ. 8vo. Minneapolis, 1890.

——. The American Neocomian and the *Gryphœa Pitcheri.* 8vo. Minneapolis, 1890.

——. The Lower and Middle Taconic of Europe and North America. 8vo. Minneapolis, 1890.

——. The Triassic Flora of Richmond, Virginia. 8vo. Minneapolis, 1890.

——. Use of the terms Laurentian and Champlain in Geology. 8vo.

——. *See* J. W. Fawkes.

*Margerie, E. de.* Note sur la Structure des Corbières. 8vo. Paris, 1890.

*Marsh, O. C.* Notice of New Tertiary Mammals. 8vo. New Haven (Conn.), 1890.

——. Notice of some extinct Testudinata. 8vo. New Haven, 1890.

——. Note on Mesozoic Mammalia. 8vo. Philadelphia, 1891.

——. Restoration of *Triceratops.* 8vo. New Haven, 1891.

——. The Gigantic *Ceratopsidæ,* or Horned Dinosaurs, of North America. 8vo. New Haven (Conn.), 1891.

Mathews, Rev. Canon. A Guide-Book to Appleby in Westmorland and its vicinity. 2nd edition. 8vo. Appleby, 1891. [Chapter V. Geology, by *J. E. Marr.*]

Maxwell, James Clerk. The Scientific Papers of. Edited by W. D. Niven. Vols. i. & ii. 4to. Cambridge, 1890. *Presented by the Clerk Maxwell Memorial Committee.*

*Meli, R.* Sopra i resti fossili di un grande Avvoltoio (*Gyps*) racchiuso nei peperini laziali. 8vo. Rome, 1889.

——. Elenco bibliografico delle più importanti pubblicazioni in cui trovasi fatta parola dei manufatti e specialmente delle terre cotte rinvenute nelle deiezioni vulcaniche del Lazio. 8vo. Rome, 1890.

*Merrill, G.* Notes on the Serpentinous Rocks of Essex County, New York. 8vo. Washington (D.C.), 1890.

*Millar, C. C. H.* The Phosphate Fields of Florida. 8vo. London, 1891.

Mingaye, C. H. Notes on some Minerals, &c. 8vo. Sydney, 1890.

Missouri. Geological Survey. (*A. Winslow*, State Geologist). Bulletin No. 1. 8vo. Jefferson City, Mo. 1890.

——. ——. ——. Bulletin No. 2. A Bibliography of the Geology of Missouri, by F. A. Samson. 8vo. Jefferson City, 1890.

——. ——. ——. Bulletin No. 3. The Clay, Stone, Lime, and Sand Industries of St. Louis City and County, by G. E. Ladd; and the Mineral Waters of Henry, St. Clair, Johnson, and Benton Counties, by A. E. Woodward. 8vo. Jefferson City, Mo., 1890.

——. ——. ——. Bulletin No. 4. A Description of some Lower Carboniferous Crinoids from Missouri, by S. A. Miller. 8vo. Jefferson City, Mo., 1891.

——. ——. ——. Biennial Report of the State Geologist transmitted by the Bureau of Geology and Mines to the 36th General Assembly, 1891. 8vo. Jefferson City, Mo., 1891.

*Moreno, F. P.* Museo de la Plata. Esploracion Arqueologica de la Provincia de Catamarca. 8vo. Buenos Aires, 1891.

*Morgan, C. Lloyd.* I. The Brislington Cutting. II. Mendip Notes. III. The Geology of the Wick Rocks Valley. 8vo. Bristol, 1890.

*Nathorst, A. G.* Kritiska anmärkningar om den Grönländska vegetationens historia. 8vo. Stockholm, 1890.

——. Några reffelobservationer i trakten af Omberg. 8vo. Stockholm, 1890.

——. Om förepomsten af *Dictyophyllum Nilssoni*, Brongn. sp., i Kinas kolförande bildningar. 8vo. Stockholm, 1890.

——. Ueber das angebliche Vorkommen von Geschieben des Hornsandsteins in den norddeutschen Diluvialablagerungen. 8vo. Mecklenburg, 1890.

——. Bemerkungen über Professor Dr. O. Drude's Aufsatz: "Betrachtungen über die hypothetischen vegetationslosen Einöden im temperirten Klima der nördlichen Hemisphäre zur Eiszeit." 8vo. Leipzig, 1891.

——. Jordens Historia efter M. Neumayr's "Erdgeschichte" utarbetad med särskild hänsyn till Nordens Urverld. Häft 6. 8vo. Stockholm, 1891.

——. Kritische Bemerkungen über die Geschichte der Vegetation Grönlands. 8vo. Leipzig, 1891.

New South Wales. *Australian Museum.* Report of Trustees for the year 1889. 4to. Sydney, 1890.

——. Department of Mines. Annual Report for the year 1889. 4to. Sydney, 1890. *Presented by the Hon. Minister of Mines.*

*Newton, E. T.* On some New Mammals fron the Red and Norwich Crags. 8vo. London, 1890.

——. On the Occurrence of Lemmings and other Rodents in the Brick-earth of the Thames Valley. 8vo. London, 1890.

New York. Geological Survey. 5th and 6th Annual Reports of the State Geologist (*James Hall*). 8vo. Albany (N.Y.), 1886 and 1887.

——. State Museum of Natural History. 39th Annual Report of the Trustees for the year 1885. 8vo. Albany (N.Y.), 1886. *Presented by Prof. James Hall, F.M.G.S.*

——. ——. 41st Annual Report of the Trustees for the year 1887. 8vo. Albany (N.Y.), 1888.

——. ——. 42nd Report of the Trustees for the year 1888. 8vo. Albany (N.Y.), 1889.

——. ——. *See* also PERIODICALS. Albany (N.Y.).

New Zealand. *Colonial Museum and Geological Survey.* Catalogue of the Colonial Museum Library. 8vo. Wellington (N.Z.), 1890.

——. ——. Reports of Geological Explorations during 1888–89. 8vo. Wellington (N.Z.), 1890.

——. ——. Studies in Biology for New Zealand Students. No. 4. The Skeleton of the New Zealand Crayfishes (*Palinurus* and *Paranephrops*), by T. J. Parker. 8vo. Wellington (N.Z.), 1889.

——. ——. 24th Annual Report on the Colonial Museum and Laboratory, together with a list of donations and deposits during 1888–89. 8vo. Wellington (N.Z.), 1890.

——. Reports on the Mining Industry in New Zealand, including Goldfields, Roads, Water-races, and other works in connection with Mining. 4to. Wellington (N.Z.), 1890. *Presented by the Mines Department.*

Nicholson, H. A., and R. Lydekker. A Manual of Palæontology. 3rd edition. 2 vols. 8vo. Edinburgh, 1889. *Purchased.*

*Norman, Mark W.* A Popular Guide to the Geology of the Isle of Wight, with a note on its relation to that of the Isle of Purbeck. 8vo. Ventnor, 1891.

Norway. *Norges Geologiske Undersögelse.* Aarbog for 1891. 8vo. Christiania, 1891.

——. ——. Selbu, af C. H. Homan. 8vo. Christiania, 1890.

——. ——. Geologiske iagttagelser fra Trondhjems stift, af H. Reusch. 8vo. Christiania, 1890.

——. ——. Salten og Ranen, af J. H. L. Vogt. 8vo. Christiania, 1891.

Norwegian North-Atlantic Expedition, 1876–78. XX. Zoology. Pycnogonidea, by G. O. Sars. *Presented by the Meteorological Institute, Christiania.* 4to. Christiania, 1891.

*Omboni, G.* Il Croccodillo Fossile (*Steneosaurus Barettoni*, Zigno) di Treschè, nei sette Comuni. 8vo. Venice, 1890.

Paléontologie Française. Série 1. Animaux Invertébrés. Terrains Tertiaires. Livr. 16. Eocène, Échinides. Tome i., par G. Cotteau. 8vo. Paris, 1889. *Purchased.*

——. ——. ——. ——. Livr. 21 et 23. Éocène, Échinides. Tome ii., par G. Cotteau. 8vo. Paris, 1890–91. *Purchased.*

——. ——. Terrain Jurassique. Livr. 87. Crinoïdes, par P. de Loriol. 8vo. Paris, 1889. *Purchased.*

——. Série 2. Végétaux. Terrain Jurassique. Livr. 40. Éphédrées, Spirangiées et Types proangiospermiques, par le Marquis de Saporta. 8vo. Paris, 1889. *Purchased.*

——. ——. ——. ——. Livr. 43, 45, et 46. Types proangiospermiques, par le Marquis de Saporta. 8vo. Paris, 1890–91. *Purchased.*

Pallas, P. S. Bemerkungen auf einer Reise in der südlichen Statthalterschaften des russischen Reichs in den Jahren 1793 und 1794. Bände 1 und 2. 4to. Leipzig, 1799 & 1801. *Purchased.*

Parker, T. J. *See* New Zealand. Colonial Museum.

*Pavlow, A.* Le Néocomien des Montagnes de Worobiewo. 8vo. Moscow, 1890.

Paul, J. D. Report of the Geological Section. Literary and Philosophical Society. 8vo. Leicester, 1882.

Pearson, W. H. *See* Canada.

Pennsylvania. *Geological Survey.* Reports AA. Atlas. Southern Anthracite Field. Part iii. 8vo. 1889.

——. ——. Report $I_5$. Seventh Report on the Oil and Gas Fields of Western Pennsylvania for 1887, 1888, by J. F. Carll. 8vo. Harrisburg (Pa.), 1890.

——. ——. Report $P_4$. Directory of the Fossils of Pennsylvania and neighbouring States, by J. P. Lesley. Vols. ii. & iii. 8vo. Harrisburg (Pa.), 1889 & 1890.

*Pettenkofer, Max v.* Rerum cognoscere causas. 4to. Munich, 1890.

*Platania, G.* Stromboli e Vulcano nel Settembre del 1889. 8vo. Riposto, 1889.

——. I fenomeni sottomarini durante l' Eruzione di Vulcano (Isole Eolie) nel 1888–89. 8vo. Acireale, 1890.

*Platania, G.* Sui projettili squarciati di Vulcano (Isole Eolie) nell' eruzione del 1888–89. 4to. Rome, 1891.

Portugal. *Commission des Travaux Géologiques.* Description de la Faune Jurassique du Portugal. Embranchement des Échinodermes, par P. de Loriol. Fasc. I. 4to. Lisbon, 1890.

——. *Commission des Travaux Géologiques du Portugal.* Description de la Faune Jurassique du Portugal. Embranchement des Échinodermes, par P. de Loriol. Fasc. 2. 4to. Lisbon, 1891.

*Prestwich, J.* On the Age, Formation, and Drift-stages of the Darent Valley. 8vo. London, 1891.

Queensland. Geological Survey. Annual progress report for the year 1889. 4to. Brisbane, 1890. *Presented by the Government Geologist, R. L. Jack, Esq., F.G.S.*

*Reade, T. Mellard.* Geological Notes on the Excursion to Anglesey, April, 1889. Boulder in Sewer Heading, Addison Street, and Mammalian Bones in Blue Clay, Alt Mouth. 8vo. Liverpool, 1890.

——. Secular Straining of the Earth in Relation to the deep Phenomena of Volcanic Action. 8vo. London, 1890.

——. List of Scientific Papers and Works by. 8vo. London, 1890.

*Renevier, E.* Envahissement graduel de la mer éocènique aux Diablerets. 8vo. Lausanne, 1891.

——. *See* Switzerland. Commission Géologique.

Reports, Colonial. British New Guinea. Despatch from His Honour the Administrator of British New Guinea [Wm. Macgregor] reporting administrative visit of Inspection to the Western Division. 4to. Brisbane, 1891. *Presented by the Secretary of State for the Colonies.*

Revel, A. I tesori sottoterranei dell' Italia, per G. Jervis. 8vo. Lausanne, 1882. *Presented by Chev. W. Jervis, F.G.S.*

*Richards, Sir G. H.* Report on the present state of the Navigation of the River Mersey (1890).

Rosenbusch, H. Petrographical Tables: an aid to the Microscopical Determination of Rock-forming Minerals. Translated and edited by *Dr. F. H. Hatch.* 4to. London, 1890.

*Rothpletz, A.* Das Karwendelgebirge. 8vo. Munich, 1888. (*See* Maps.)

Russia. *Comité Géologique.* Bulletins. 1889. Tome viii. Nos. 6–10. 8vo. St. Petersburg, 1889–90.

——. ——. ——. 1890. Tome ix. Nos. 1–6. 1890.

——. ——. ——. Supplément au Tome ix. Bibliothèque Géologique de la Russie, 1889, par S. Nikitin. 1890.

——. ——. Mémoires. Vol. ix. No. 1. (Blatt 48.) Melitopol, &c , von N. Sokolow und E. Fedorow. 4to. St. Petersburg, 1889.

——. ——. ——. Vol. xi. No. 1. (Blatt 126.) Perm-Solikamsk, von A. Krasnopolsky. 4to. St. Petersburg, 1889.

*Rütimeyer, L.* Uebersicht der eocänen Fauna von Egerkingen, nebst einer Erwiderung an Prof. E. D. Cope, 8vo. Basel, 1890.

*Sacco, F.* I Molluschi dei terreni terziarii del Piemonte e della Liguria. Parte VIII. 8vo. Turin, 1890.

——. La géotectonique de la Haute-Italie occidentale. 8vo. Brussels, 1890.

——. Louis Bellardi. Note Biographique. 8vo. Brussels, 1890.

*Scudder, S. H.* Physiognomy of the American Tertiary Hemiptera. 8vo. Boston, 1889.

——. The Fossil Insects of North America. 2 vols. 4to. New York, 1890.

*Seeley, H. G.* Handbook of the London Geological Field Class. 8vo. London, 1891.

*Sherborn, C. Davies.* See *Burrows, H. W.*, *Woodward, A. Smith*, and Serials. London. Geologists' Association.

*Solly, H. S., and J. F. Walker.* Note on the Fault in the Cliff west of Bridport Harbour. 8vo. Dorchester, 1890.

South Australia. Geological Map of the Tertiary Deposits of the Hundred of Barossa, with Explanatory Notes by *H. Y. L. Brown*, Government Geologist. 4to. Adelaide, 1889.

——. Report of Geological Examination of country in the neighbourhood of Alice Springs, by *H. Y. L. Brown*, Government Geologist. 8vo. Adelaide, 1890.

——. Report on Journey from Warrina to Musgrave Ranges, by *H. Y. L. Brown*, Government Geologist. 4to. Adelaide, 1890.

——. See *Brown, H. Y. L.*

Spain. *Comisión del Mapa Geológico de España.* Boletin. Tomo iii. Cuaderno 2. 8vo. Madrid, 1876.

——. ——. ——. Tomo xvi. 1890.

——. ——. Memorias. Descripcion fisica y geológica de la Provincia de Huesca, por L. Mallada. 8vo. Madrid, 1878.

——. ——. ——. Descripcion fisica, geológica, y minera de la Provincia de Huelva, por D. J. Gonzalo y Tarin. Tomo 2. Parte 3. 8vo. Madrid, 1888.

*Spencer, J. W.* Elevations in the Dominion of Canada. 8vo. Washington (D.C.), 1884.

——. Niagara Fossils. Vol. i. No. 1. 8vo. St. Louis, Mo., 1884.

——. The Mississippi River during the Great River Age. 8vo. 1884.

——. Occurrence of Boulders of Decomposition at Washington, D.C. 8vo. Philadelphia, 1885.

——. Hummocks and Boulders of Decomposition in South-eastern Missouri. 8vo. London, 1887.

——. Notes on the Erosive Power of Glaciers, as seen in Norway. 8vo. London, 1887.

——. Notes upon Ice-action in High Latitudes. 8vo. London, 1888.

——. The Iroquois Beach: a Chapter in the Geological History of Lake Ontario. 8vo. Montreal, 1889.

——. Origin of the Basins of the Great Lakes of America. 8vo. London, 1890.

——. The Deformation of Iroquois Beach and Birth of Lake Ontario. 8vo. New Haven (Conn.), 1890.

——. "Southern Drift" and its Agricultural Relations. 8vo. Atlanta (Ga.), 1890.

——. The High Continental Elevation preceding the Pleistocene Period (in America). 8vo. London, 1890.

——. Deformation of the Algonquin Beach, and Birth of Lake Huron. 8vo. New Haven (Conn.), 1891.

——. High Level Shores in the Region of the Great Lakes, and their Deformation. 8vo. New Haven (Conn.), 1891.

——. Post-pliocene Subsidence *versus* Glacial Dams. 8vo. Rochester (N.Y.), 1891.

*Spencer, J. W.*, Sir A. C. Ramsay, Sir J. Ball, Sir R. I. Murchison, B. Studer, A. Favre, and E. Whymper. Upon the Origin of Alpine and Italian Lakes; and upon Glacial Erosion. Parts 1 & 2. 8vo. New York, 1890.

Stainton, H. T. *See* Buckler, W.

*Stanley, W. F.* Surveying and Levelling Instruments Theoretically and Practically Described. 8vo. London, 1890.

*Stapff, F. M.* Diluvialstudien in Lappmarken. 8vo. Leipzig, 1891.

*Steenstrup, J.* Die Mammuthjäger-station bei Předmost im österreichischen Kronlande Mähren nach einem Besuche daselbst im Juni–Juli 1888. 4to. Vienna, 1890.

*Stirling, J.* Notes on the Hydrology of the Mitta Mitta. 8vo. Melbourne, 1890.

*Stopes, H.* Indications of Retrogression in Prehistoric Civilization in the Thames Valley. 8vo. Leeds, 1890.

Sweden. *Sveriges Geologiska Undersökning.* Ser. A *a*. Kartblad i skalen 1 : 50000. Beskrifningar. Nos. 84, 100, 103–107. 8vo. Stockholm, 1889.

——. ——. Ser. B *b*. Specialkartor. Beskrifningar. No. 4. 4to. Stockholm, 1889.

——. ——. ——. No. 6. 8vo. Stockholm, 1890.

——. ——. Ser. C. Affandlingar och uppsatser. Nos. 93–98, 100 & 101, 103–111, 113–115. 8vo. Stockholm, 1889–90.

——. ——. ——. Nos. 92, 99, 102. 4to. Stockholm, 1888–89.

Switzerland. *Commission Géologique.* Matériaux pour la Carte géologique de la Suisse. Livraison 16. Monographie des Hautes-Alpes vaudoises, par E. Renevier. 4to. Bern, 1890.

*Teller, F.* Ueber den Schädel eines fossilen Dipnoërs, *Ceratodus Sturii*, nov. spec., aus den Schichten der oberen Trias der Nordalpen. 4to. Vienna, 1891.

*Toula, F.* Geologische Untersuchungen im centralen Balkan. III. Petrographischer Theil von A. Rosiwall. 4to. Vienna, 1890.

——. Geologische Untersuchungen im östlichen Balkan und in den angrenzenden Gebieten. 4to. Vienna, 1890.

——. ——. 8vo. Stuttgart, 1890.

——. Reisen und geologische Untersuchungen in Bulgarien. 8vo. Vienna, 1890.

Townsend, C. C. The Mineral Wealth of India. 8vo. Bombay, 1891. *Purchased.*

*Trechmann, C. O.* Twins of Marcasite in regular disposition upon Cubes of Pyrites. 8vo. London, 1891.

*Tschermak, G.* Die Chloritgruppe. I. u. II. Theil. 8vo. Vienna, 1890 & 1891.

*Tyrrell, J. B.* Foraminifera and Radiolaria from the Cretaceous of Manitoba. 4to. Montreal, 1890.

*Ulrich, G. H. F.* On the Discovery, Mode of Occurrence, and Distribution of the Nickel-Iron Alloy Awaruite, on the west coast of the South Island of New Zealand. 8vo. London, 1890.

United States. *Department of the Interior. United States Geological Survey.* 8th Annual Report 1886–87. Parts 1 & 2. J. W. Powell, Director. 8vo. Washington (D.C.), 1889.

——. ——. ——. 9th Annual Report, 1887–88. J. W. Powell, Director. 8vo. Washington (D.C.), 1889.

——. ——. ——. J. W. Powell, Director. Bulletin. Nos. 54–62, 64 & 66. 8vo. Washington (D.C.), 1889–90.

——. ——. ——. Mineral Resources of the United States. Calendar, year 1888, D. T. Day. 8vo. Washington (D.C.), 1890.

——. ——. ——. Monographs. Vol. i. Lake Bonneville, by G. K. Gilbert. 4vo. Washington (D.C.), 1890.

——. ——. ——. Monographs. Vol. xv. The Potomac or Younger Mesozoic Flora, by W. M. Fontaine. Text and Plates. 4to. Washington (D.C.), 1889.

——. ——. ——. ——. Vol. xvi. The Palæozoic Fishes of North America, by J. S. Newberry. 4to. Washington (D.C.), 1889.

——. Engineer Department, U.S. Army. United States Geographical Surveys west of the 100th Meridian. *Capt. G. M. Wheeler in charge.* Vol. i. Geographical Report. 4to. Washington, 1889.

*Upham, W.* Artesian Wells in North and South Dakota. 8vo. Minneapolis, 1890.

——. On the Cause of the Glacial Period. 8vo. Minneapolis, 1890.

——. Report of Exploration of the Glacial Lake Agassiz, in Manitoba. 8vo. Montreal, 1890.

——. The Fiords and Great Lake Basins of North America, considered as evidence of Preglacial Continental Elevation and of Depression during the Glacial Period. 8vo. ——, 1890?

*Upham, W., F. Leverett, N. S. Shaler,* and *W. O. Crosby.* Discussion of the Climatic Conditions of the Glacial Period. 8vo. Salem, Mass., 1890.

*Ussher, W. A. E.* The Triassic Rocks of West Somerset and the Devonian Rocks on their Borders. 8vo. Taunton, 1890.

Vallée, Poussin de la. Compte-rendu de la Session extraordinaire de la Société Géologique de Belgique, tenue à Dinant, Septembre 1888. 8vo. Liége, 1890. *Presented by Prof. G. Dewalque, F.M.G.S.*

*Van Overloop, E.* *See* PERIODICALS. Brussels. Société Belge de Géologie, &c.

Victoria. Mining Department. Annual Report of the Secretary for Mines to the Hon. D. Gillies, M.P., *Minister of Mines for Victoria,* including Reports on the working of the Regulation and Inspection of Mines &c. for the year 1889. 4to. Melbourne, 1890.

——. ——. Reports and Statistics for the quarter ended 31st March, 1890. 4to. Melbourne, 1890. *Presented by the Minister for Mines.*

——. ——. Reports and Statistics for the quarter ended 30th June, 1890. 4to. Melbourne, 1890. *Presented by the Minister for Mines.*

——. ——. Reports and Statistics for the quarter ended 30th September, 1890. 4to. Melbourne, 1890. *Presented by the Minister for Mines.*

——. ——. Reports and Statistics for the quarter ended 31st December, 1890. 4to. Melbourne, 1891. *Presented by the Minister for Mines.*

Virchow, R. The Veddás of Ceylon. 8vo. Colombo, 1888. *Presented by the Ceylon Branch of the Royal Asiatic Society.*

*Wähner, F.* Beiträge zur Kenntniss der tieferen Zonen des unteren Lias in den nordöstlichen Alpen. 4to. Vienna, 1890.

*Walcott, C. D.* Description of New Forms of Upper Cambrian Fossils. 8vo. Washington, 1890.

Walther, J. Die Denudation in der Wüste und ihre geologische Bedeutung. 8vo. Leipzig, 1891. *Purchased.*

*Weinschenk, E.* Ueber Serpentine aus den östlichen Central-Alpen und deren Contactbildungen. 8vo. Munich, 1891.

Western Australia. Annual General Report for 1888–89, by *H. P. Woodward,* Government Geologist. 8vo. Perth (W.A.), 1890.

——. ——. ——. *Presented by the Secretary of State for the Colonies.*

Western Australia. Western Australian Year-book for 1889, by W. A. Gale. 8vo. Perth (W.A.), 1890. *Presented by Dr. H. Woodward, F.R.S., F.G.S.*

——. Catalogue of Exhibits at the International Exhibition of Mining and Metallurgy, London, 1890. With an Appendix containing an account of the Principal Mining Districts of the Colony, by *H. P. Woodward*, Government Geologist. 8vo. Perth (W.A.), 1890.

Williams, G. H. *See* Bell, R.

*Wilson, E.* Fossil Types in the Bristol Museum. 8vo. London, 1890.

——. Guide to the Bristol Museum. 8vo. Bristol, 1890.

*Winchell, A.* Recent Observations on some Canadian Rocks. 8vo. Minneapolis, 1890.

——. Recent Views about Glaciers. 8vo. New York, 1890.

*Winchell, N. H.* What constitutes the Taconic Range of Mountains. 8vo. Minneapolis, 1890.

Woodward, A. Smith. *See* British Museum, and *Sherborn, C. Davies.*

*Woodward, A. Smith*, and *C. Davies Sherborn.* A Catalogue of British Fossil Vertebrata. Supplement for 1890. 8vo. London, 1891.

*Woodward, B. B.* On the Pleistocene (non-Marine) Mollusca of the London District. 8vo. London, 1890.

*Woodward, H.*, A. H. Foord, H. A. Nicholson, and G. J. Hinde. Notes on the Palæontology of Western Australia. 8vo. London, 1890.

*Woodward, H.* Obituary Notice of W. S. Dallas. 1890. [Geol. Mag.] Slip &c.

Woodward, H. B. *See* PERIODICALS. London, Geologists' Association.

*Woodward, H. P.* *See* Western Australia.

Woodward, Samuel. [Notice.] A Geologist of a Century Ago. 8vo. London, 1891. *Presented by Dr. H. Woodward, F.R.S., F.G.S.*

Yarkand Mission. Scientific Results of the Second Yarkand Mission; based upon the collections and notes of the late Ferdinand Stoliczka. Coleoptera. 4to. Calcutta, 1890. *Presented by the Government of India.*

*Yates, L. G.* Notes on the Geology and Scenery of the Islands forming the southerly line of the Santa Barbara Channel. 8vo. Minneapolis, 1889.

*Yates, L. G.* Channel Islands [California]. 8vo. 9th Ann. Rep. State Min. ? 1890.

Zeiller, R. *See* France. Ministère des Travaux Publics.

*Zigno, Barone A. de.* Chelonii Terziari del Veneto. Venice, 1890.

Zincken, C. F. Das Vorkommen der natürlichen Kohlenwasserstoff- und der anderen Erdgase. 4to. Halle, 1890. *Presented by the K. Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher.*

---

## 3. Maps, &c.

*Names of Donors in Italics.*

Bavaria. Geognostische Karte des Königreichs Bayern. Blatt No. xvii. Ansbach, 1891. *Presented by the Bavarian Survey.*

Canada. *See* Books.

France. Carte géologique détaillée de la France. Nos. 28, 74, 89, 90, 97, 105, 120, 121, 140, 152, 168, 177, 183, 236, 247. Scale $\frac{1}{80000}$. *Purchased.*

——. Dépôt de la Marine. 27 Charts and Plans of various coasts and ports.

*Harrison, J. B.*, and *A. J. Jukes-Browne.* Geological Map of Barbados. Scale $1\frac{1}{3}$ inch to a mile.

Italy. *See* Books. Italy.

Japan. *Imperial Geological Survey* (Noshomusho). Zone 9, Col. 10. Asuke. Scale $\frac{1}{200000}$.

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Spain. *Comision del Mapa Geologico.* [16-sheet Map. Scale $\frac{1}{4000000}$.] Hojas Nos. 6, 8, 12, 16.

——. ——. [64-sheet Map. Scale $\frac{1}{400000}$.] Hojas Nos. 19, 20, 23, 24, 27, 28, 31, 32.

*Rothpletz, A.* Geologische Karte des Karwendelgebirges. $\frac{1}{50000}$. (*See* Books.)

Russia. *Comité Géologique.* Carte géologique générale de la Russie d'Europe. Feuille 48. $\frac{1}{420000}$. 1889.

Saxony. *Geologische Landesuntersuchung des Königreichs Sachsens.* Geologische Specialkarte. Blätt. 33, 34, 35, 51, 52, 69, 119, and 143. Scale $\frac{1}{25000}$.

Sweden. *Sveriges Geologiska Undersökning.* Karta. Ser. A *a.* Bladet 84, 100, 103, 104, 105, 106, and 107. Skala $\frac{1}{50000}$.

——. ——. Praktisk-geologisk Karta öfver Fersta och Gustafsberg. Skala $\frac{1}{10000}$.

*Woodward, H. B., and J. G. Goodchild.* Geological Map of England and Wales.